A long journey toward seismic safety and sustainability

From mantle/lithosphere dynamics, earthquake modelling through seismic hazard/risk assessments to disaster risk reduction

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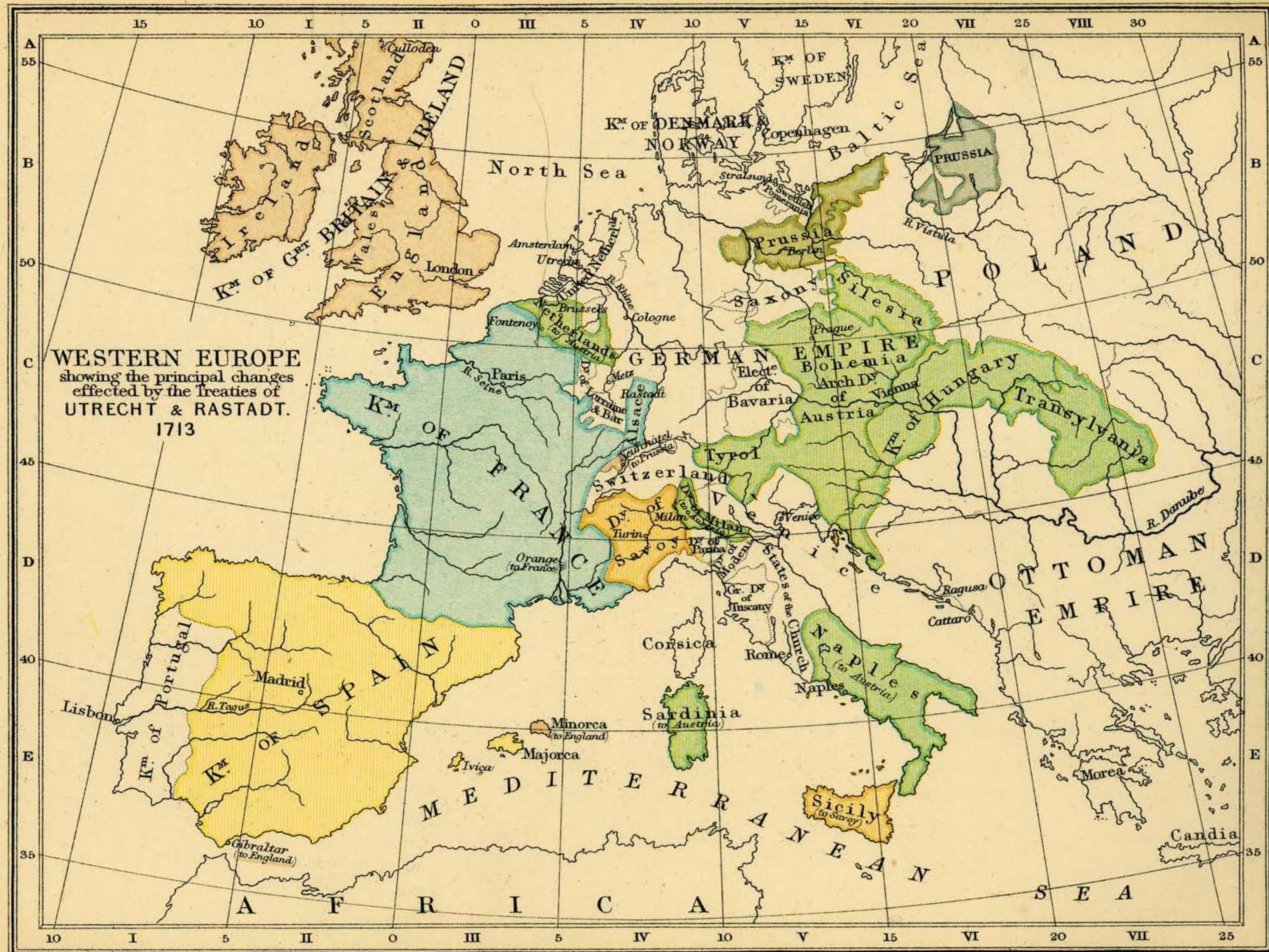
6CNIS & 2CNISS, Bucharest, Romania, 16 June 2017



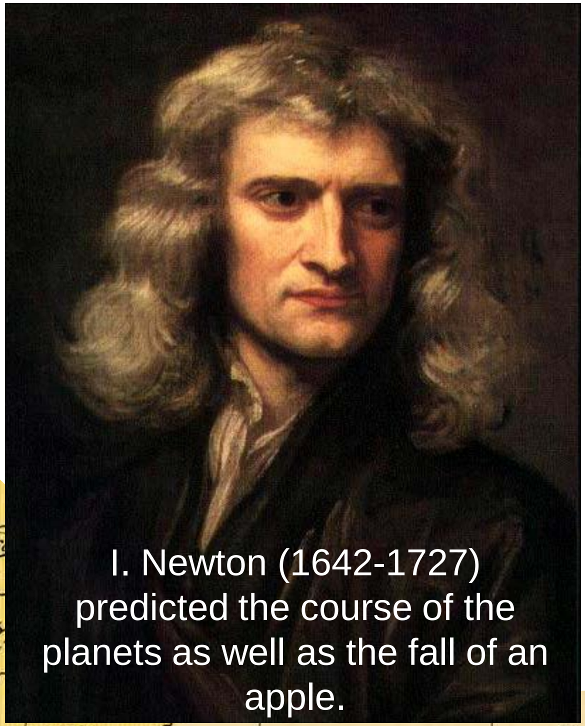
Morris's Age of Anne

Longmans, Green & Co. London, New York & Bombay.

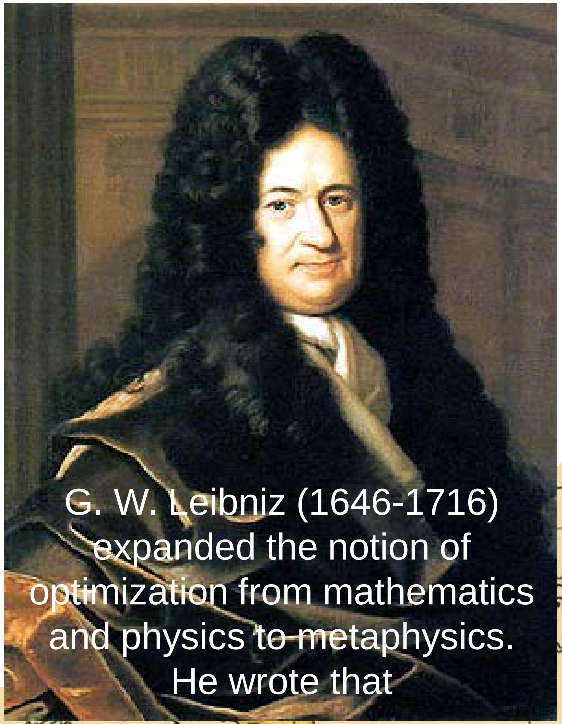
The Age of Enlightenment

The world appeared to become stable, calculable and predictable.

Two eminent scientists stand for this spirit of the 18th century.



I. Newton (1642-1727) predicted the course of the planets as well as the fall of an apple.



G. W. Leibniz (1646-1716) expanded the notion of optimization from mathematics and physics to metaphysics. He wrote that

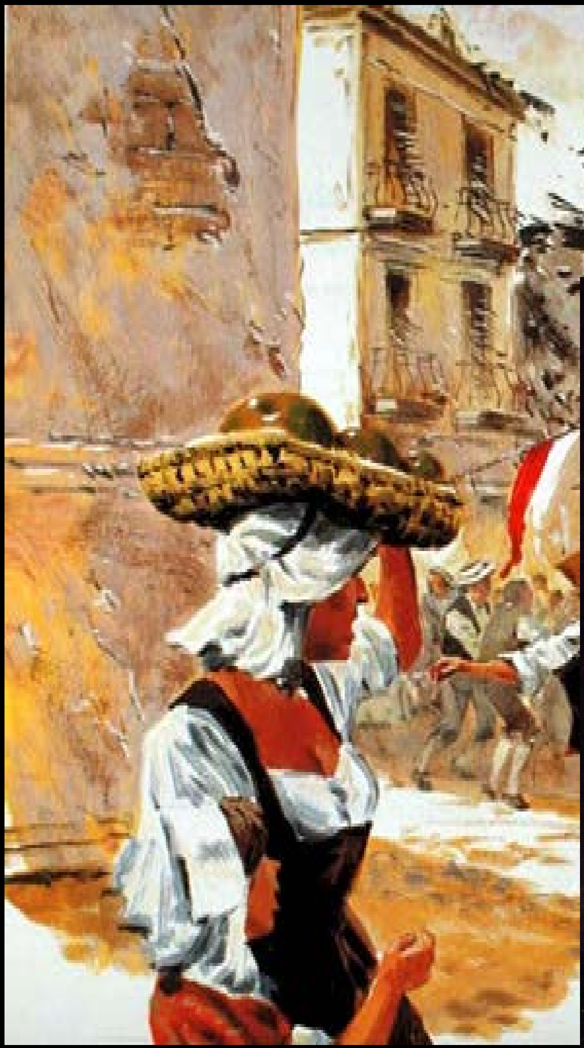
We live in the best of all possible worlds

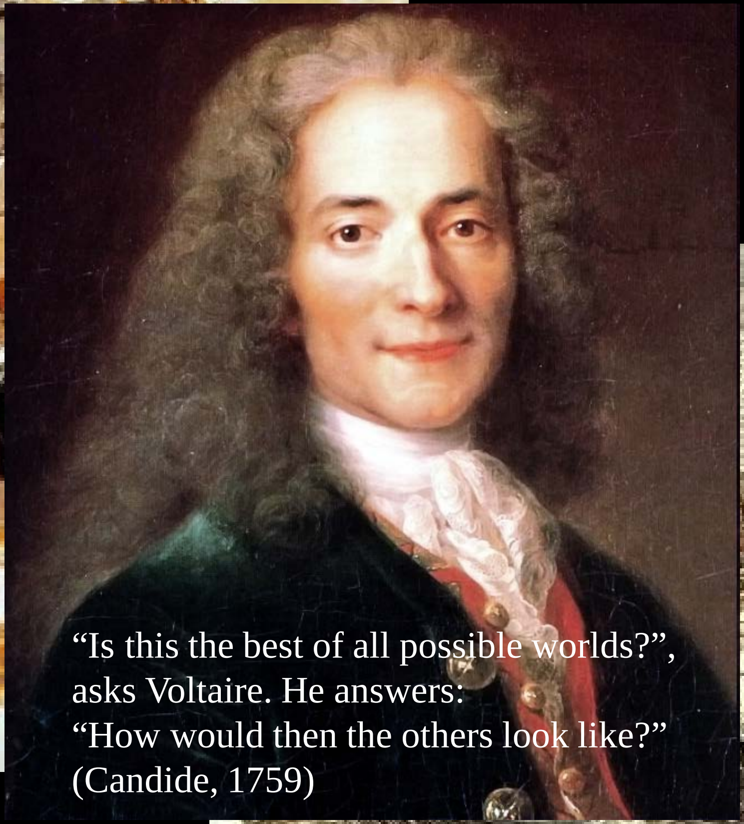
The Notion of Risk

developed in Europe assumed that the future depends on human decisions rather than on providence with a chance to loose or to win.

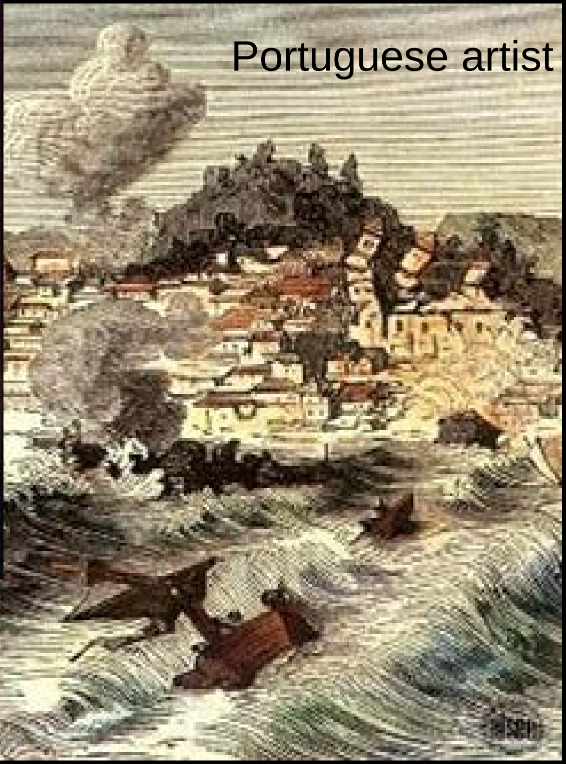
P. Fermat and B. Pascal introduced new concepts of probability and developed a theory **to control the incalculable future** (or to make **predictions with a quantifiable risk)**

Lisbon, 1 November 1755



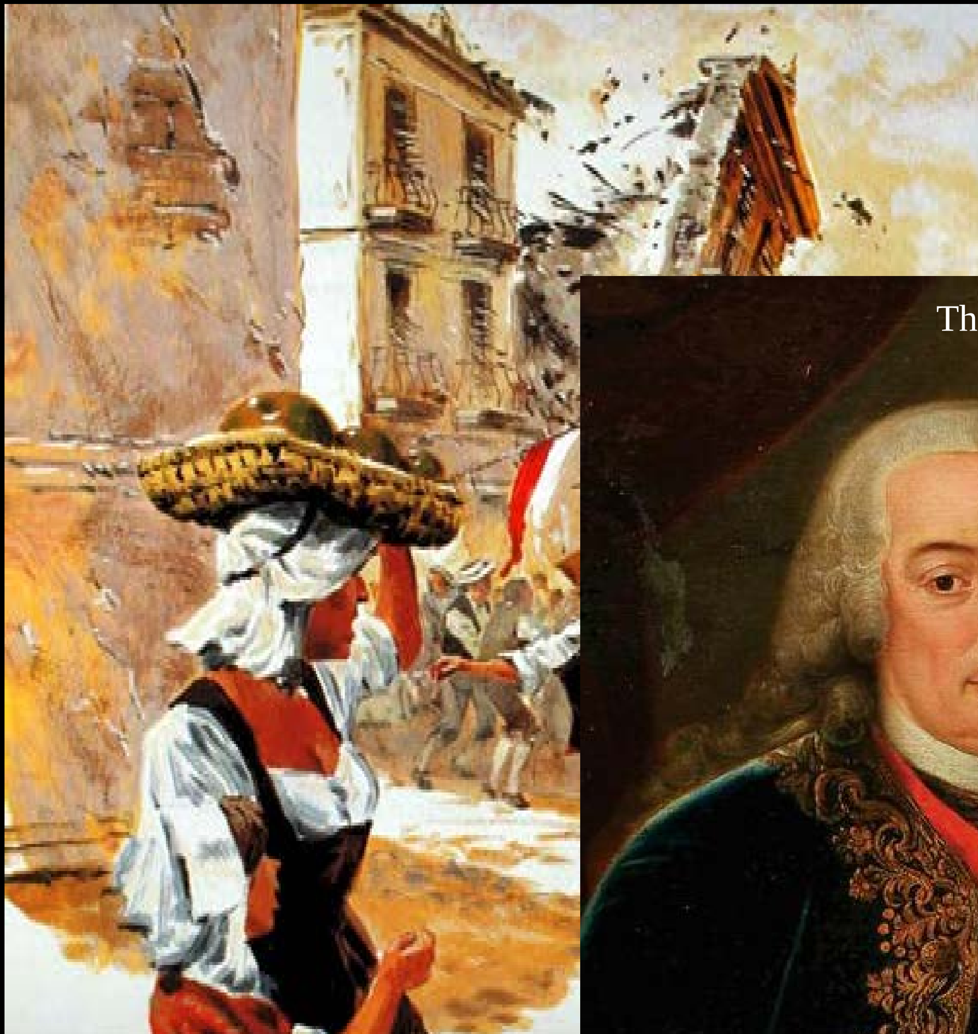


“Is this the best of all possible worlds?”,
asks Voltaire. He answers:
“How would then the others look like?”
(Candide, 1759)



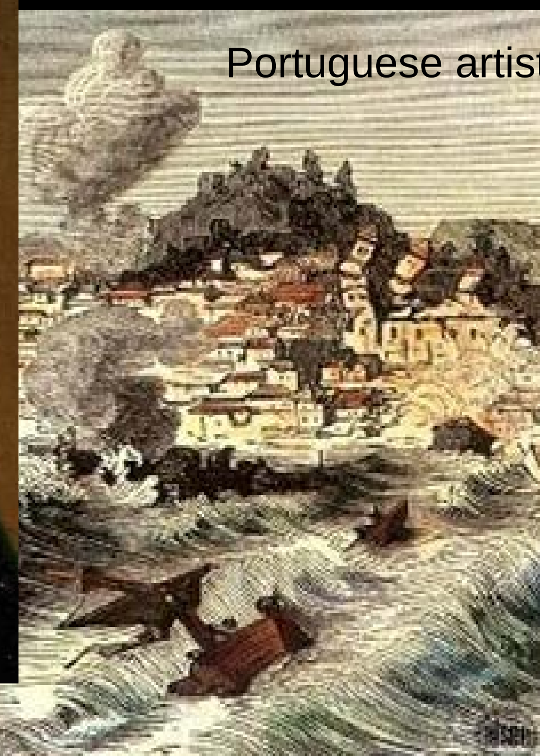
Portuguese artist

Lisbon, 1 November 1755



The Marquês of Pombal

Disaster Management Plan for Lisbon



Portuguese artist

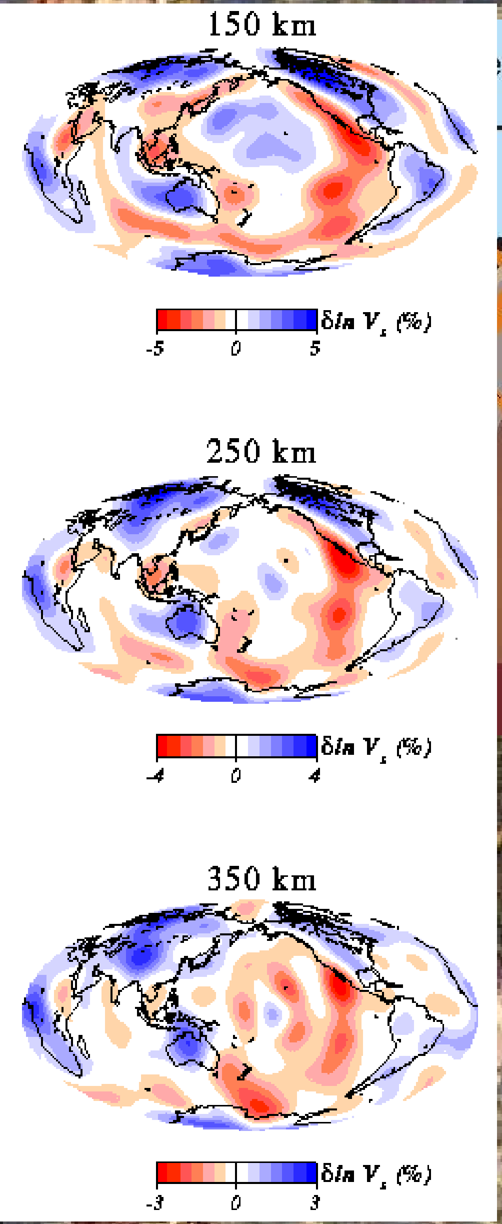
The 2011 Great East Japan M9.0 earthquake, followed by tsunami, flooding, and nuclear incident, turned to become a disaster …

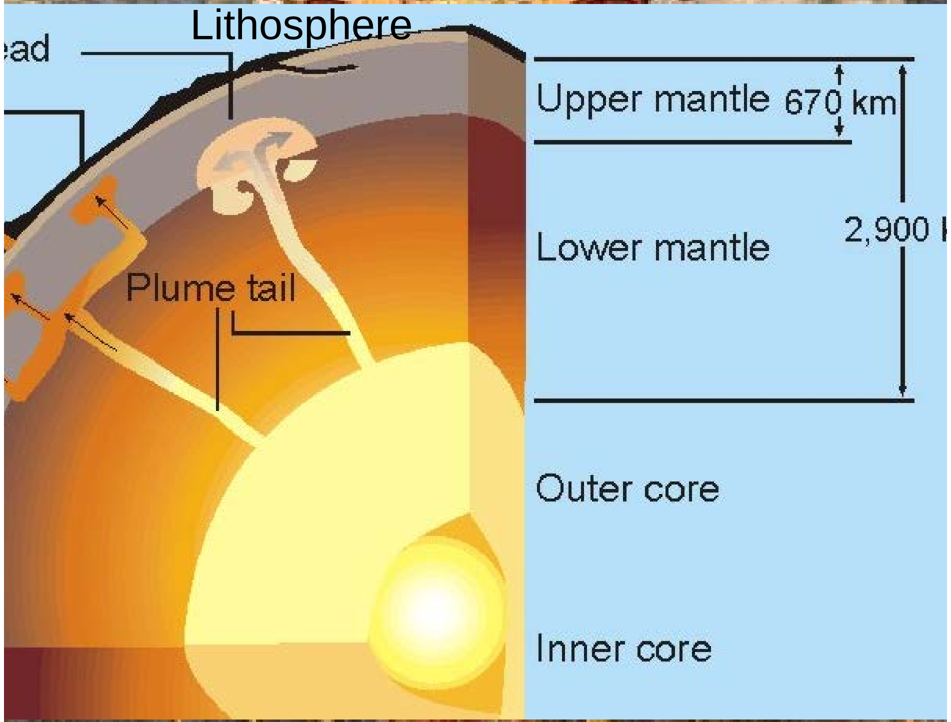
National Geographic

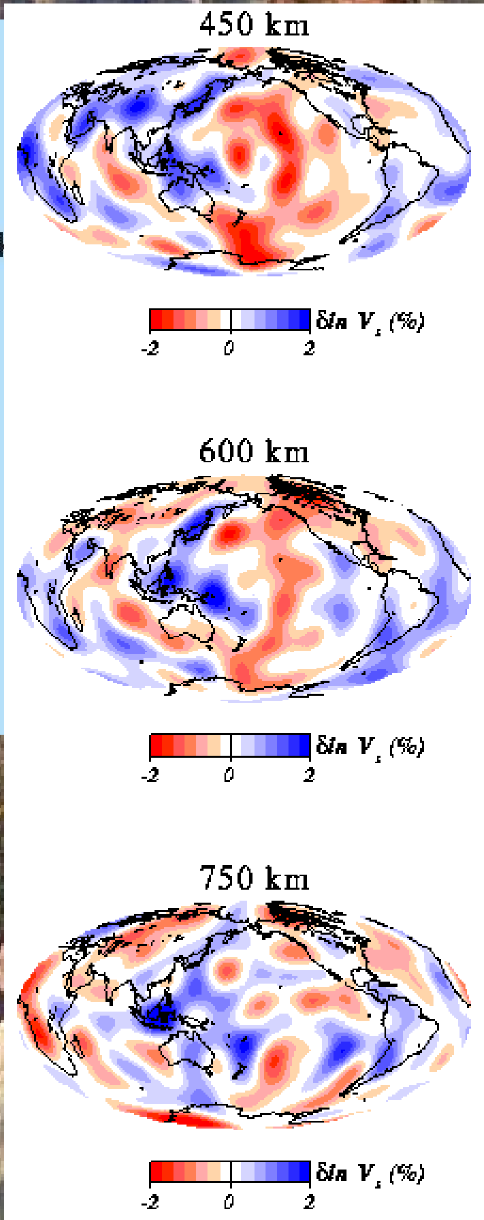
Outline of the Talk

- Introduction: understanding large earthquake occurrence
- Earthquake modeling and forecasting
- Seismic hazards and associated risk
- Earthquake vulnerability and safety
- Integrated research on disaster risks
- What should be yet done to “stop” earthquakes becoming a disaster?

"Imagination is more important than knowledge."
(Albert Einstein)



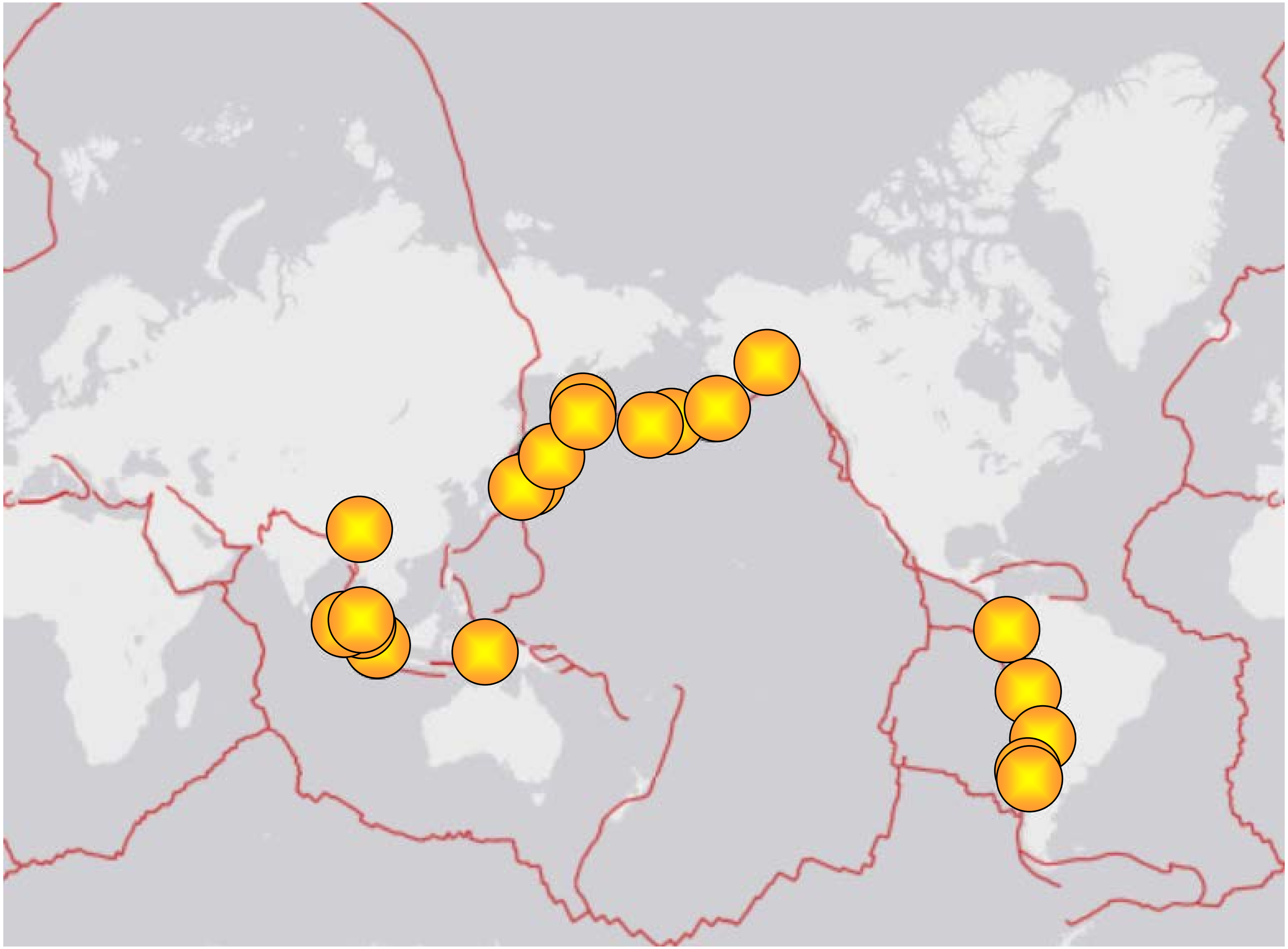




“Imagination is more important than knowledge.”
(Albert Einstein)

20 Largest Recorded Earthquakes in the World

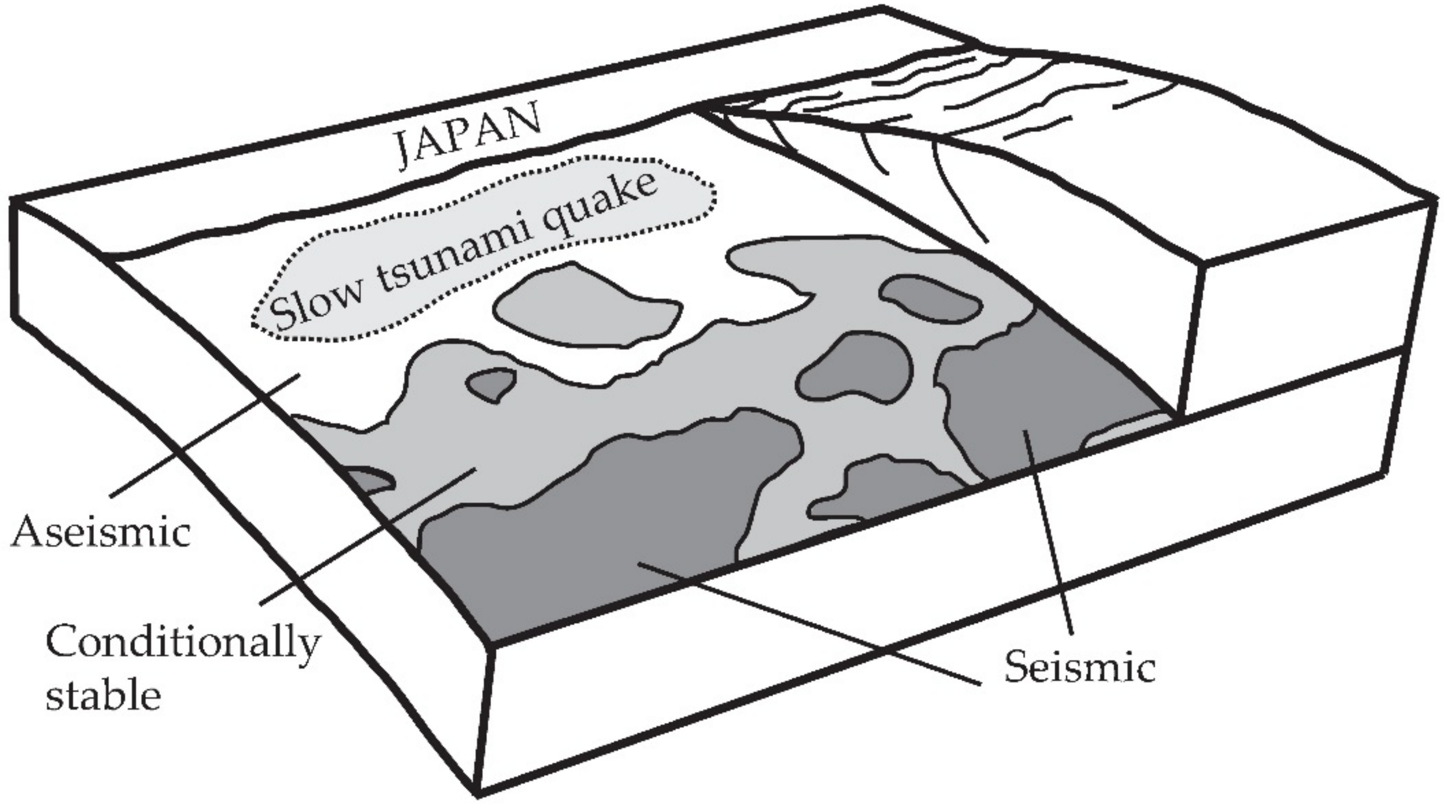
(M ≥ 8.4, 1906-2012)



Source: USGS Earthquake Hazard Program

WHERE and WHEN does a large earthquake occur?

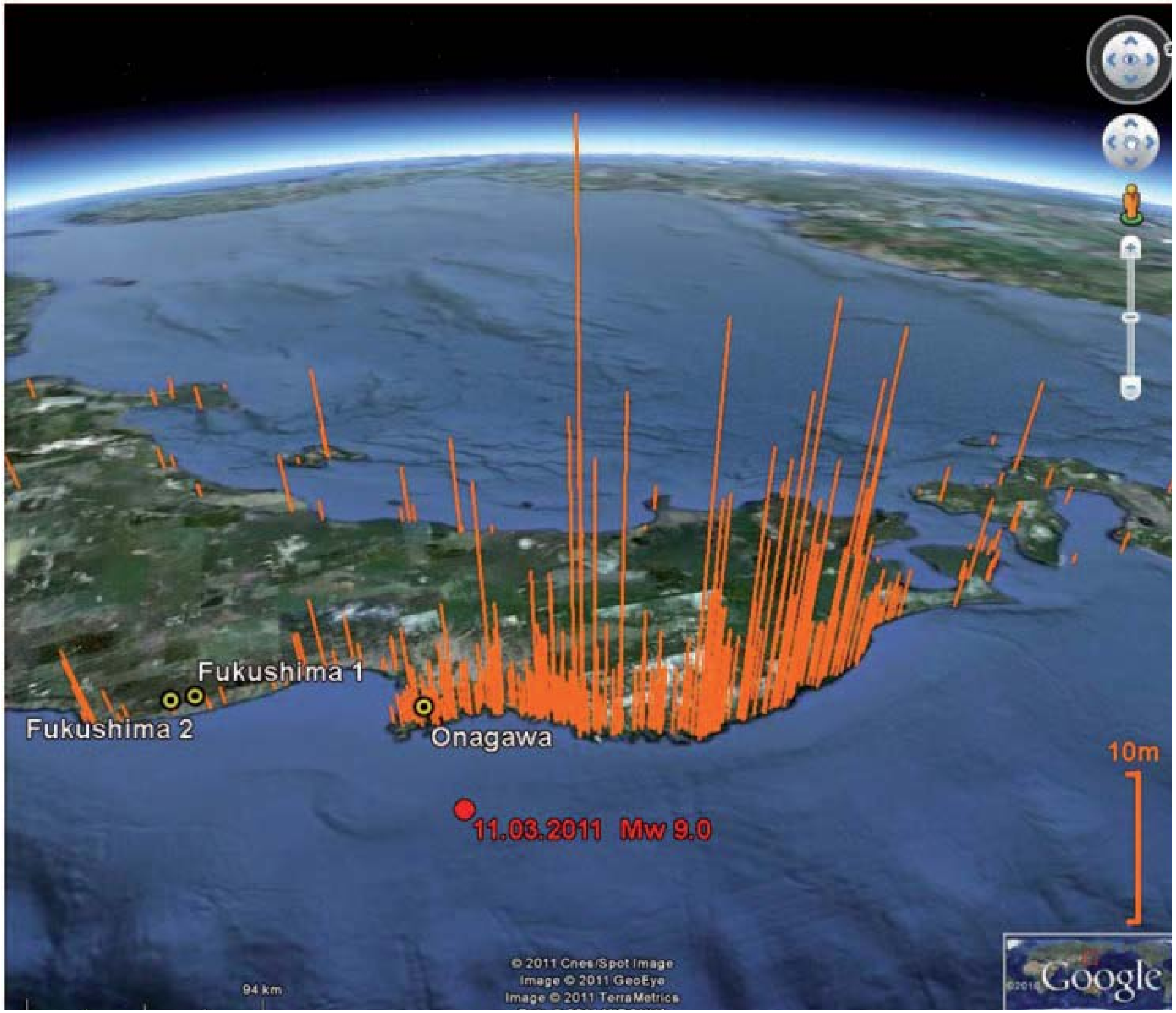
Understanding Large Earthquake Occurence Using Physics of Rupture



The megathrust off the coast of Japan comprises regions that slip ***seismically***, regions that slip ***aseismically*** (slow-rupturing regions that experience large slip at shallow depths generating tsunami earthquakes), and ***conditionally stable*** regions that slip aseismically unless adjacent slips drive them to slide seismically.

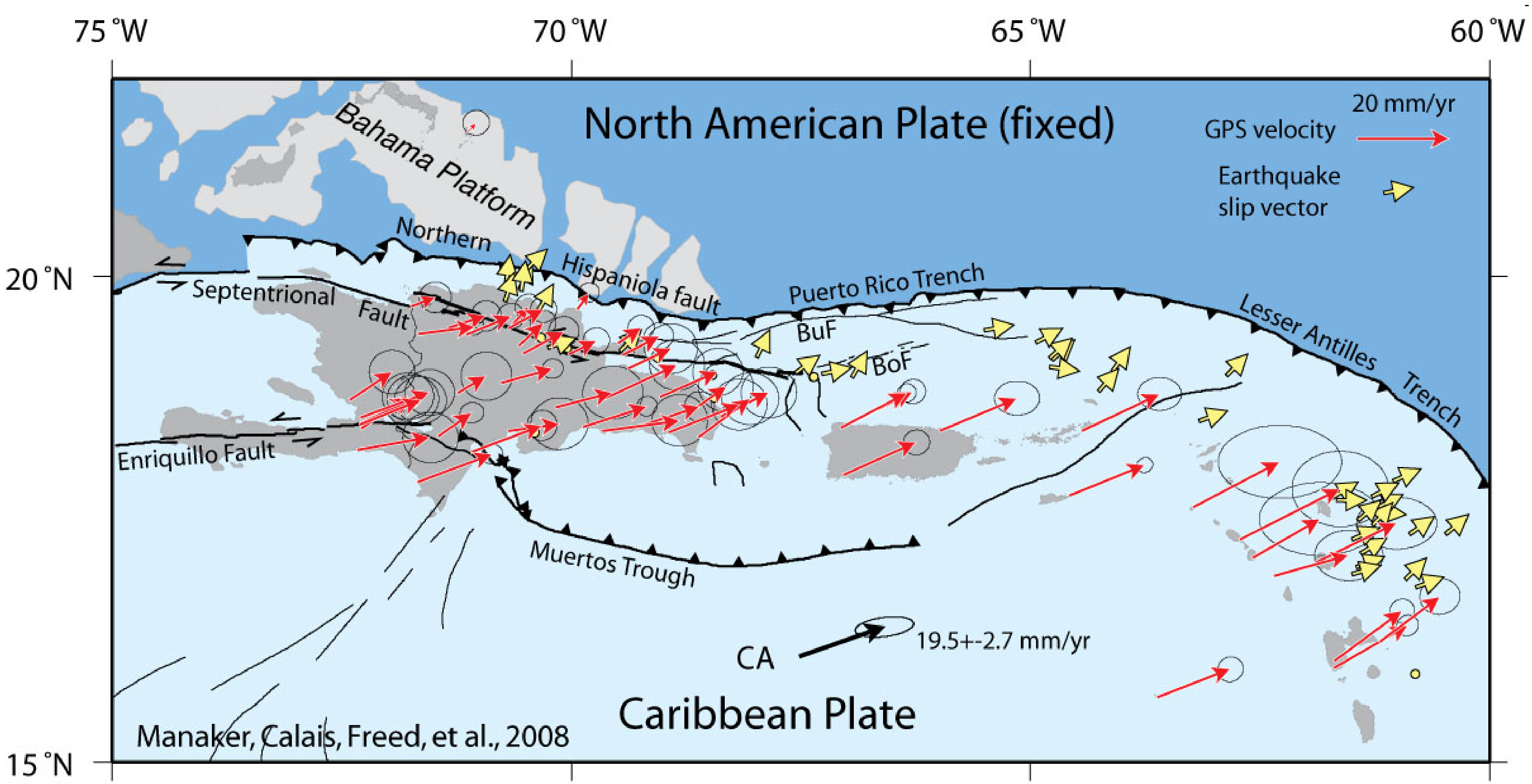
Lay and Kanamori, Physics Today, 2011

Understanding of Large Earthquake Occurence and Flooding Comes from Tsunami Data Analysis



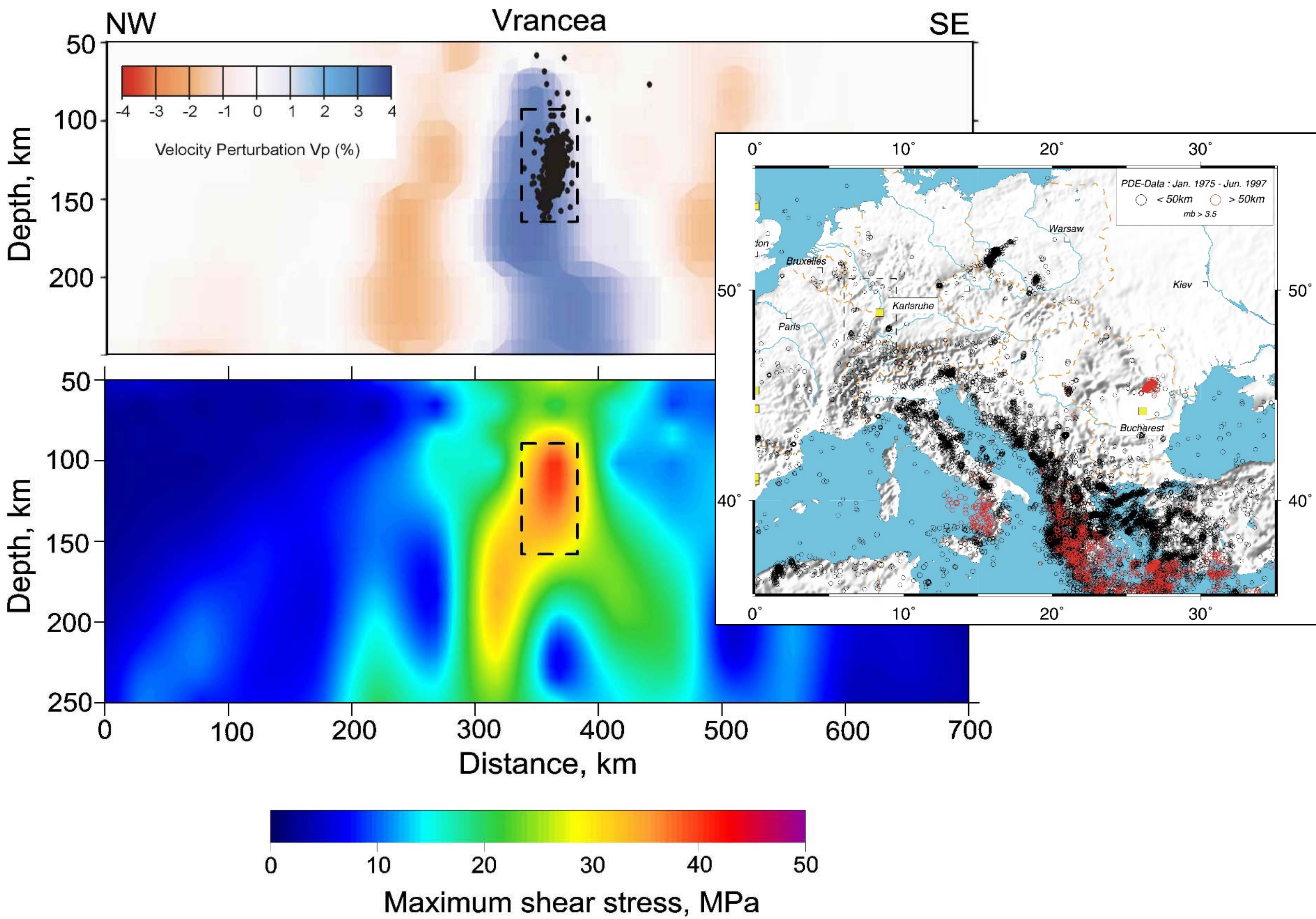
A map of reported historical tsunami run-ups along the Tohoku coast for the time period from AD 800 until 1965 (Noeggerath et al., Bull Atom. Sc, 2011)

Understanding of Earthquake Preparation Processes comes from GPS Geodesy



"… the Enriquillo fault in Haiti is currently capable of a Mw7.2 earthquake if the entire elastic strain accumulated since the last major earthquake was released in a single event today" (Manaker et al., GJI, 2008)

Understanding of Strong Earthquake Preparation Processes - Stress Modeling



Ismail-Zadeh et al., PEPI, 2005

Understanding of Earthquake Preparation Processes Using Earthquake Modeling

Simulation of realistic earthquake catalogs for an earthquake-prone region is of a great importance. The catalogs of synthetic events over a large time window can assist in interpreting the seismic cycle behavior and/or in predicting a future extreme event, as the available observations cover only a short time interval. If a segment of the catalog of modeled events approximates the observed seismic sequence with a sufficient accuracy, the part of the catalog immediately following this segment might be used to predict the future seismicity and to analyse and to forecast extreme events.

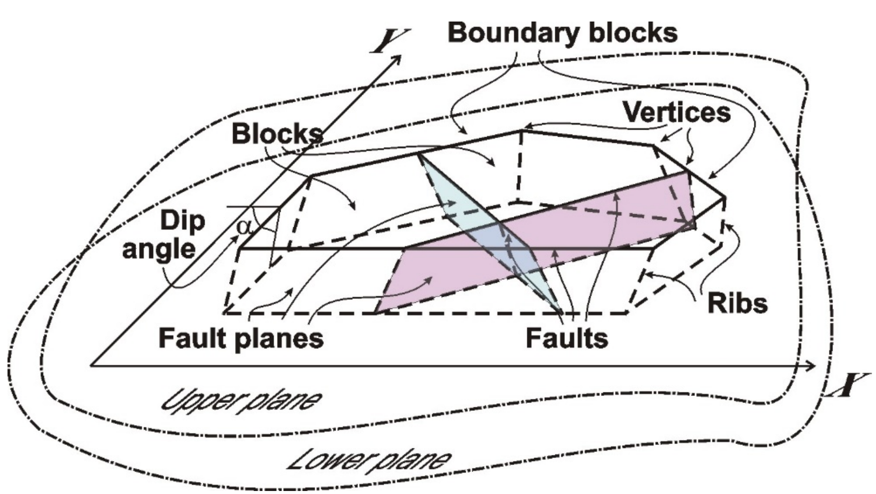
Catalogs of modeled seismic events allow to analyze

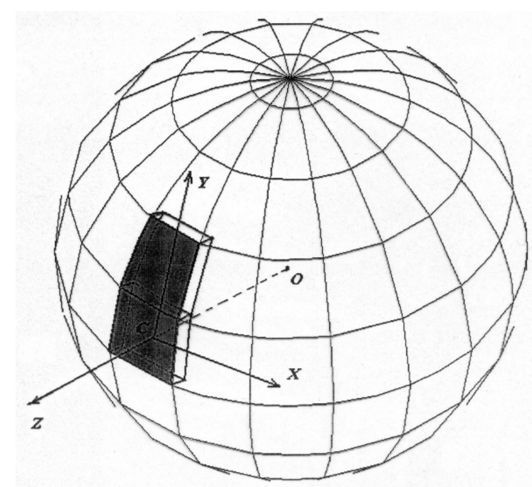
- Spatial-temporal correlation between earthquakes
- Earthquake clustering
- Occurrence of large seismic events
- Long-range interaction between the events
- Fault slip rates
- Mechanism of earthquakes
- Seismic moment release

*B*lock-*A*nd-*F*ault *D*ynamics (BAFD) Model: Basic Principles

(Gabrielov et al., 1990; Soloviev & Ismail-Zadeh, 2003; Ismail-Zadeh et al., 2012; 2017)

- The Earth's lithosphere is considered as a structure of perfectly rigid blocks divided by infinitely thin fault planes. The blocks interact between themselves and with the underlying asthenosphere.
- The structure of the blocks moves in response to a prescribed block movements and an asthenosperic flow. Displacements are small comparing with block sizes, the geometry of the structure does not change during numerical simulations.
- Deformation is localized in the fault zones, and relative block displacements take place along the fault planes. Three types of interaction are considered between blocks: visco-elastic, stress-drop, and creep.



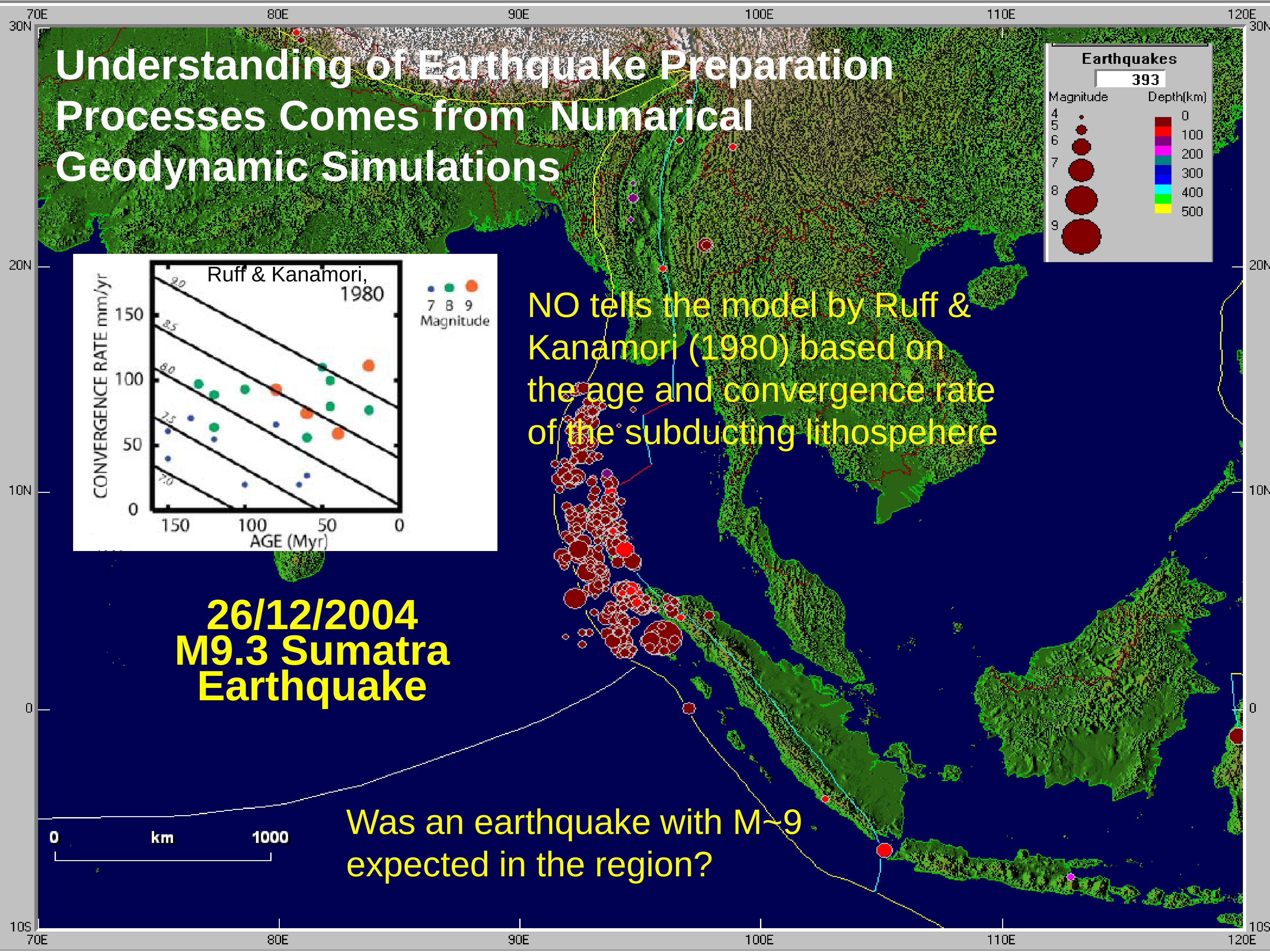


Understanding of Earthquake Preparation Processes Comes from Numarical Geodynamic Simulations

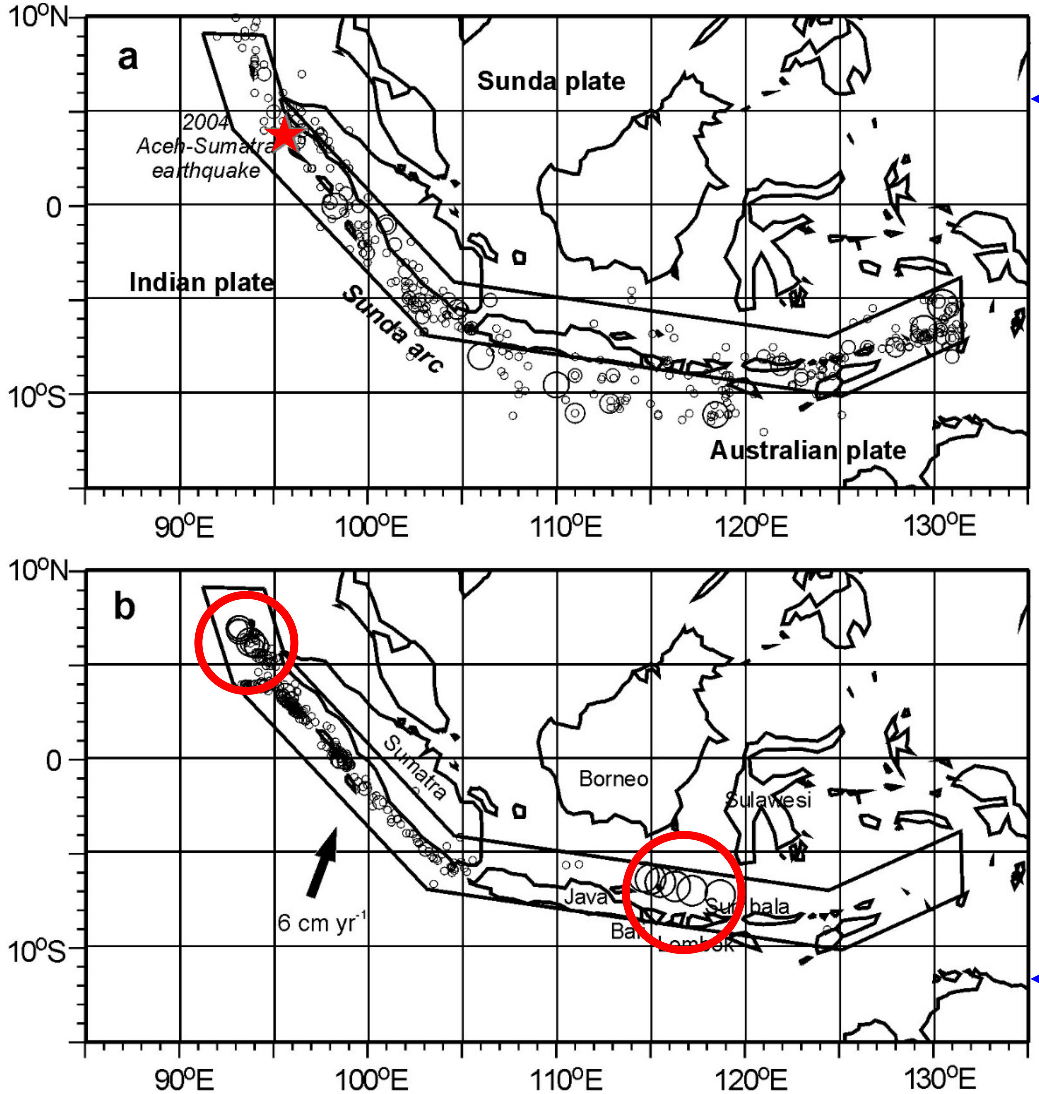
NO tells the model by Ruff & Kanamori (1980) based on the age and convergence rate of the subducting lithospehere

26/12/2004 M9.3 Sumatra Earthquake

Was an earthquake with M~9 expected in the region?

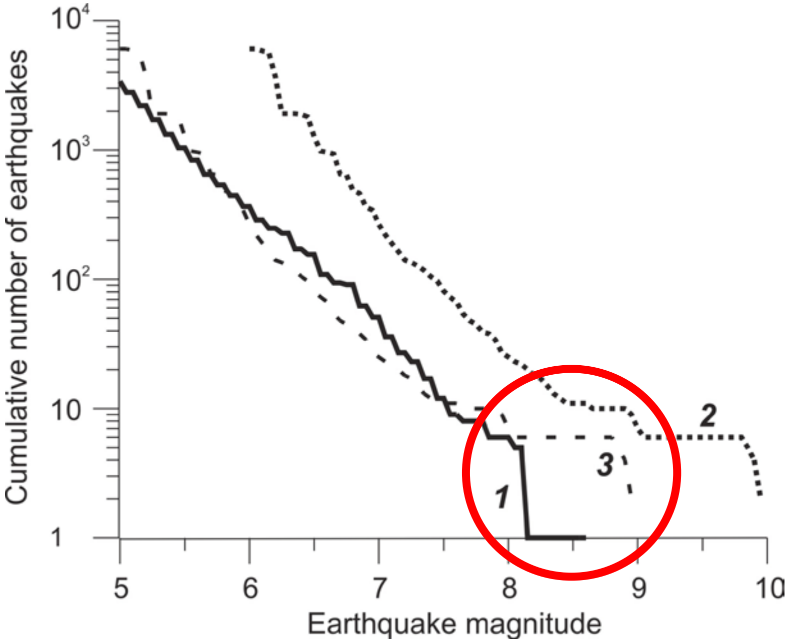


Understanding of Seismic Hazard using Earthquake Simulators (BAFD model)



Observed seismicity, M>6

Synthetic seismicity, M>7

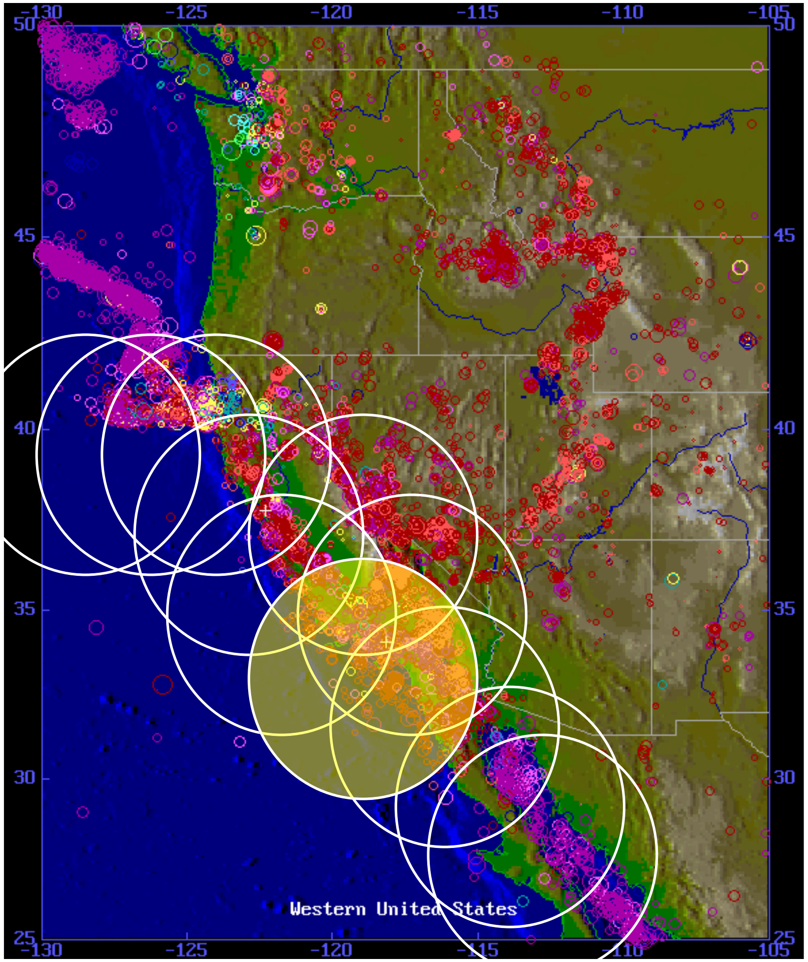


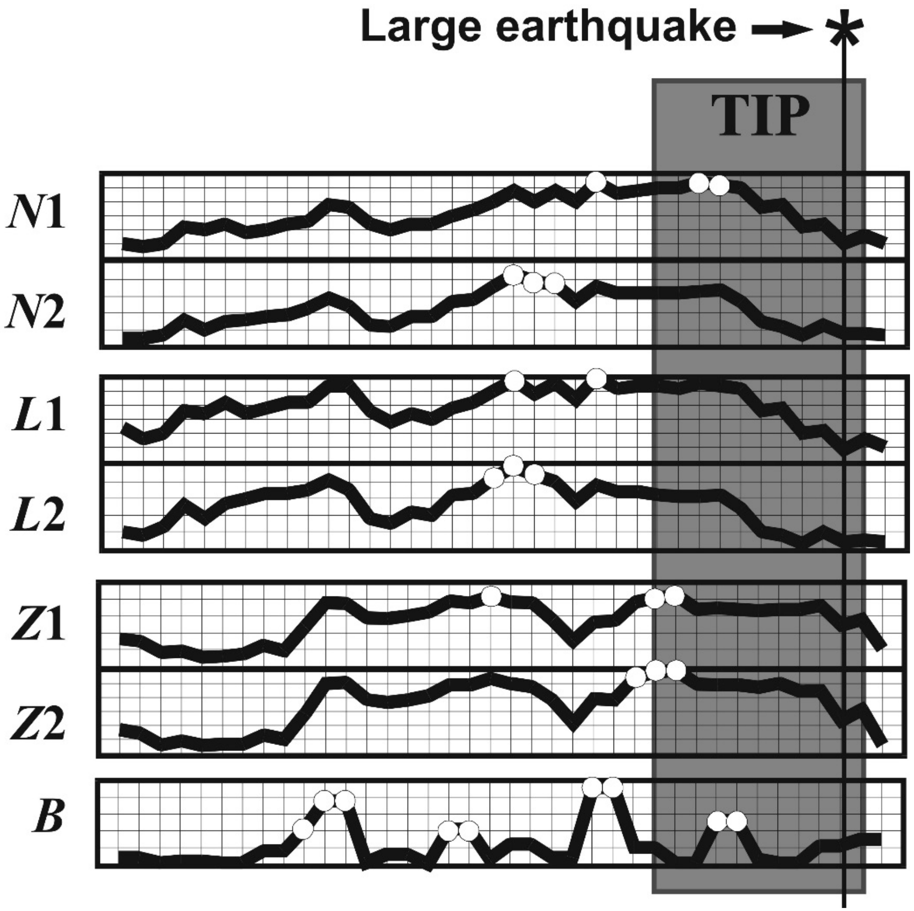
(Soloviev and Ismail-Zadeh, 2003)

Can Strong Earthquakes be Predicted?

Why forecasts are required?

Intermediate-term Large Earthquake Prediction





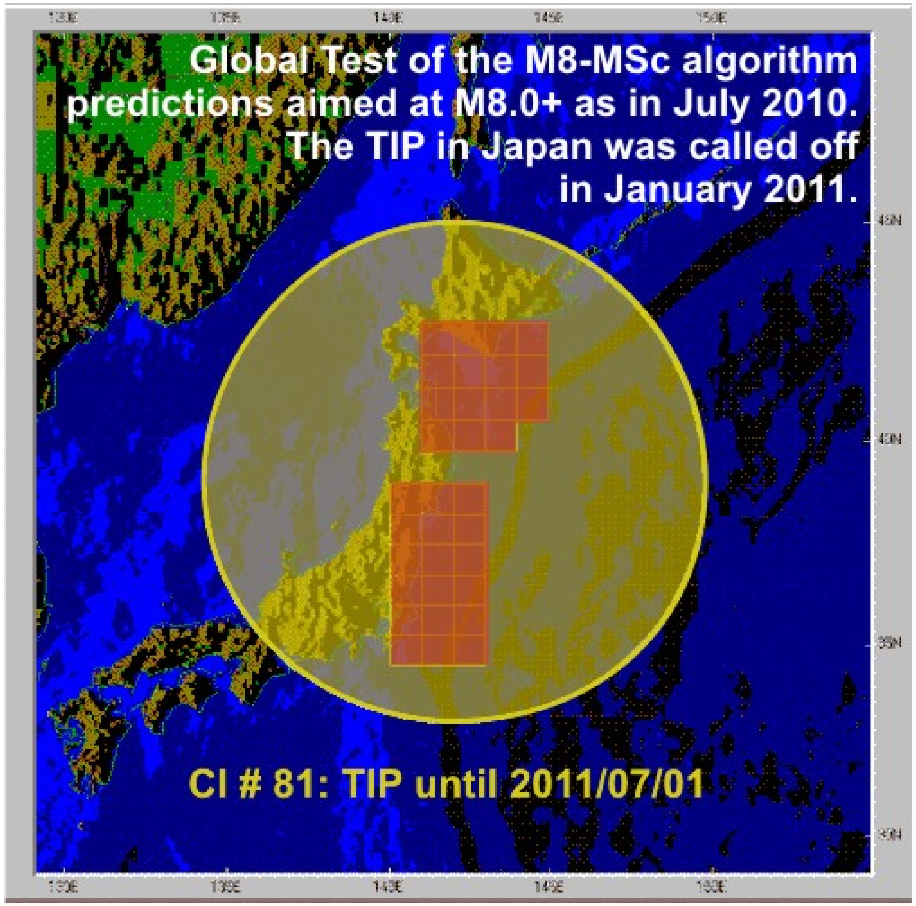
Keilis-Borok and Kossobokov, 1990

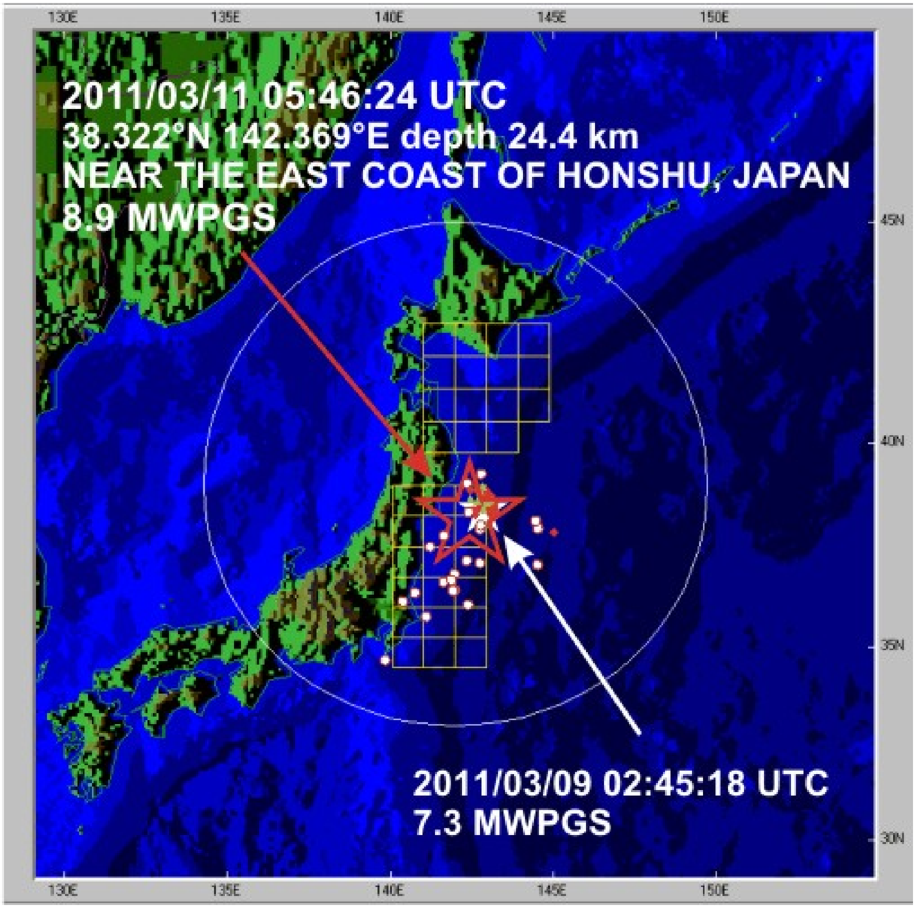
N the number of earthquakes of magnitude ***M**** or greater; ***N**** the annual number of earthquakes
L the deviation of ***N*** from longer-term trend; ***Z*** estimated as the ratio of the average source diameter to the average distance between sources; ***B*** the maximum number of aftershocks.
Each of the functions *N*, *L*, and *Z* is calculated twice with $M^* = M_{min}(N^*)$ for $N^* = N1$ and $N^* = N2$.

Intermediate-term Large Earthquake Prediction

An example: the 2011 Great East Japan Earthquake

(the earthquake was *nearly* predicted)





Courtesy: V. Kossobokov

Intermediate-term Large Earthquake Prediction

Performance of the M8 earthquake prediction algorithm

(17 of 25 great earthquake were predicted;
more than 2/3 of large events)

Test period	Large earthquakes			Alarms, %		Probability of successful prediction by a chance, %	
	Predicted by		Total				
	M8	M8-MSc		M8	M8-MSc	M8	M8-MSc
1985-2015	17	11	25	32.84	16.62	0.03	0.12

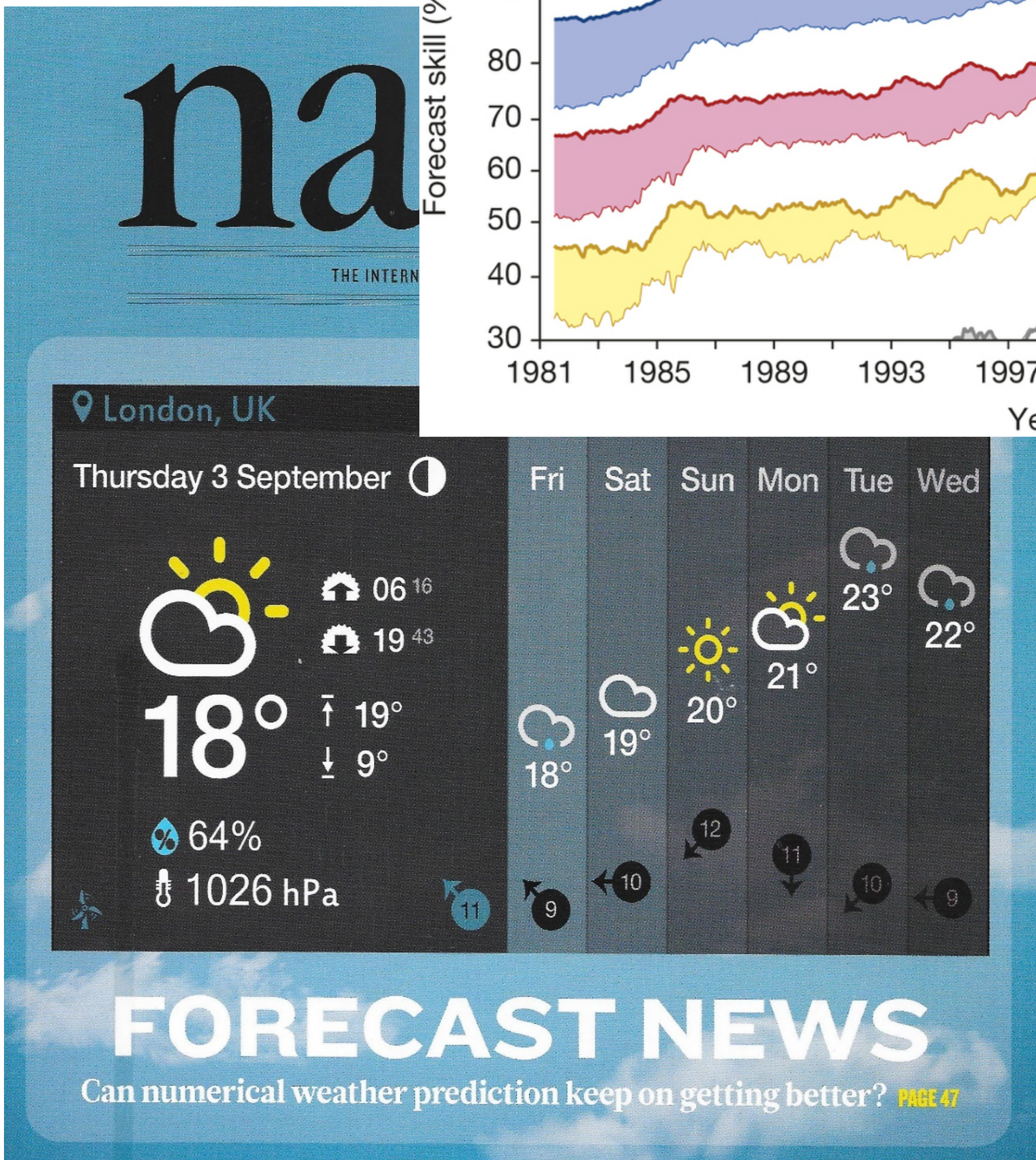
Courtesy: V. Kossobokov

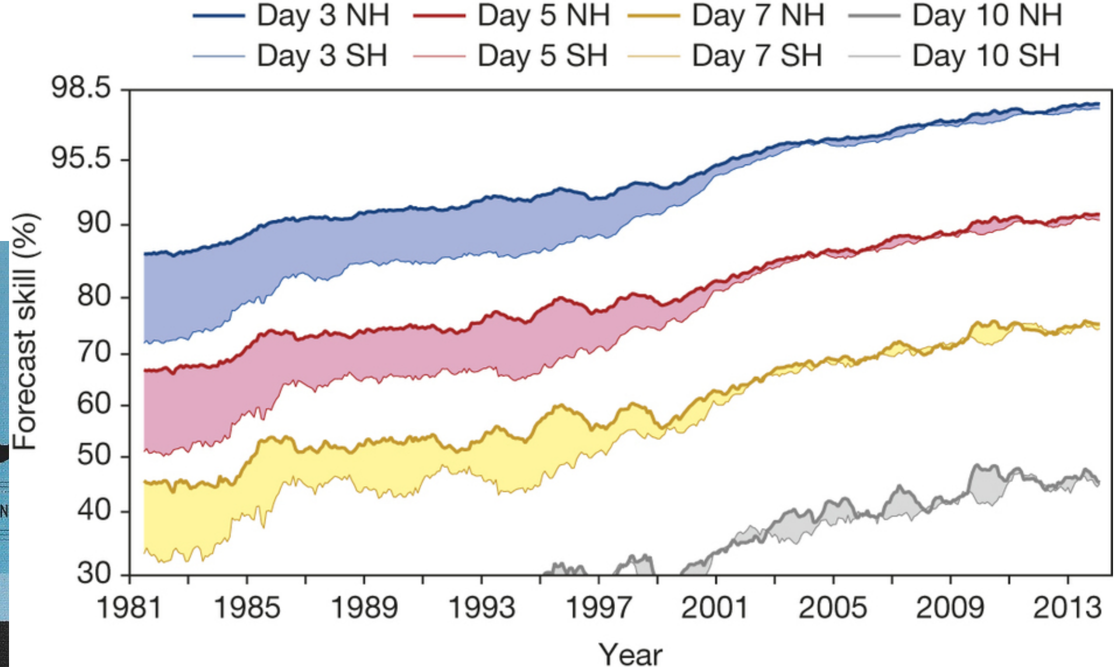
Question:

What is missing in earthquake prediction research?

Answer

comes from … meteorology…





Success in weather prediction is based on:

+ success in understanding of physics of the meteorological and related processes as well as vast observations at different scales

+ full mathematical description (Navier-Stokes, mass continuity, heat balance …)

+ great success in computer science and numerical modeling

(Bauer et al., 2015)

Major Challenges in Forecasting of Earthquake Hazards

Success in earthquake hazard forecasting can be achieved by enhancement in:

+ the physics of forecasting (understanding of stress generation, its localization and release, at all scales)

+ a mathematical description of the processes leading to earthquake and extremes (governing equations, ensemble forecasting ?)

+ model development (incl. numerical methods and supercomputer power to allow fault interaction at the scale of 50-100 m or less)

+ more geophysical, seismological and geodetic observations

"Accurate forecasts save lives, support emergency management and mitigation of impacts and prevent economic losses from high-impact weather… Their substantial benefits far outweigh the costs of investing in the essential scientific research, super-computing facilities and satellite and other observational programmes that are needed to produce such forecasts" (Bauer et al., 2015)

Question:

Can seismic hazard and risk be forecast?

Before answering it

let us look at *definitions*

Earthquake hazard could be defined as a seismic "phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Disaster is a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

(UN General Assembly, 2017)

Seismic Hazard Assessment

Seismic hazard assessment in terms of engineering parameters of strong ground motion, e.g., peak ground acceleration (PGA) or seismic intensity, is based on the information about the features of earthquake ground motion excitation, seismic wave propagate on (attenuation), and site effect in the region under consideration and combines the results of seismological, geomorphological, geological, and tectonic investigations.

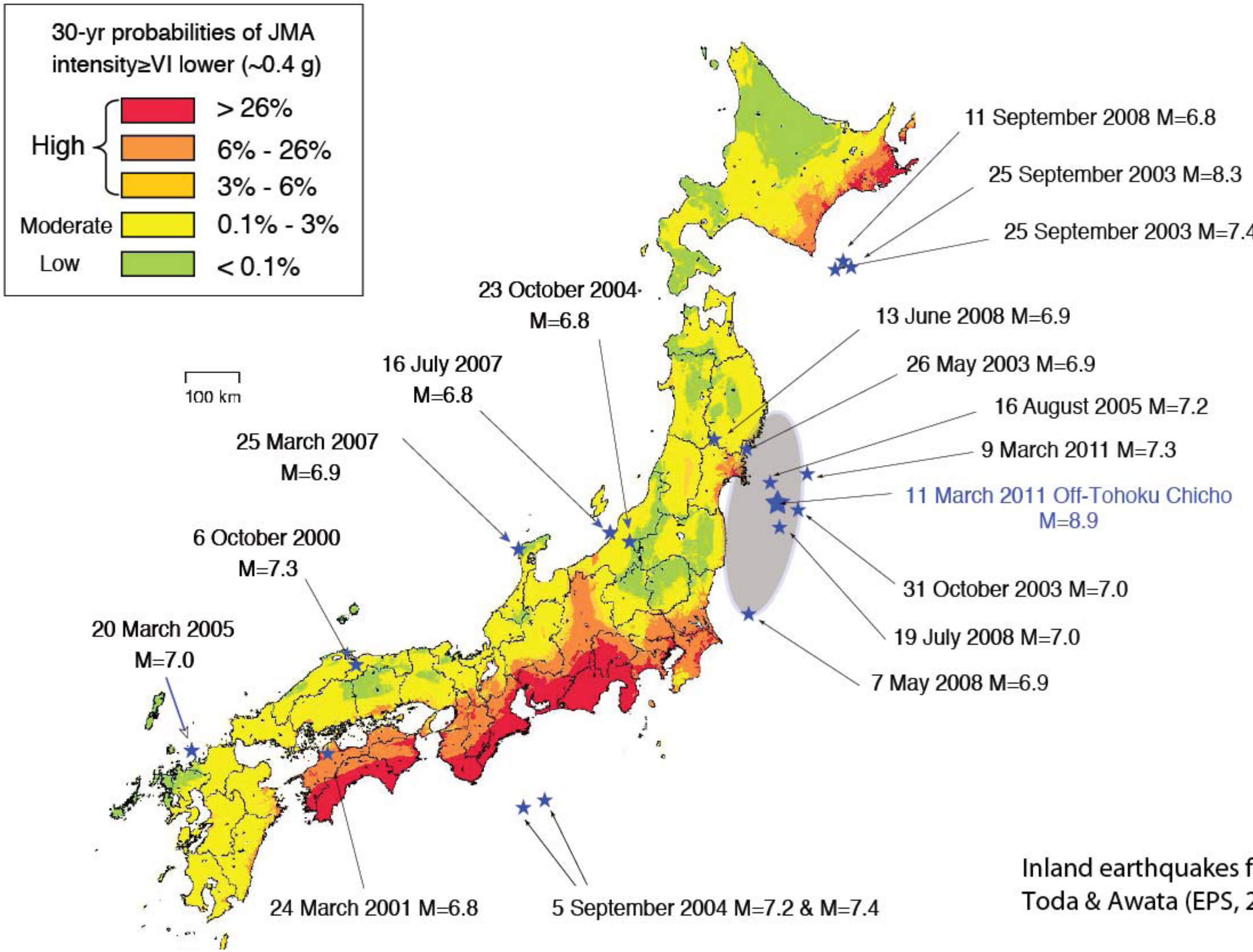
Two ***principal*** methods are intensively used in seismic hazard assessment: ***deterministic (DSHA) and probabilistic (PSHA)***.

DSHA is based on specified earthquake scenario(s). For a given earthquake, the DSHA model analyses the attenuation of seismic energy with distance to determine the level of ground motion at a particular site. Ground motion calculations capture often the effects of local site conditions and use the available knowledge on earthquake sources and wave propagation processes.

PSHA determines the probability of exceeding various levels of ground motion estimated over a specified period of time. PSHA considers uncertainties in earthquake source, path, and site conditions. However …

PROBABILISTIC SEISMIC HAZARD ASSESSMENT

How well has the 2005 Japanese National Seismic Hazard Map forecast the last decade of earthquakes?



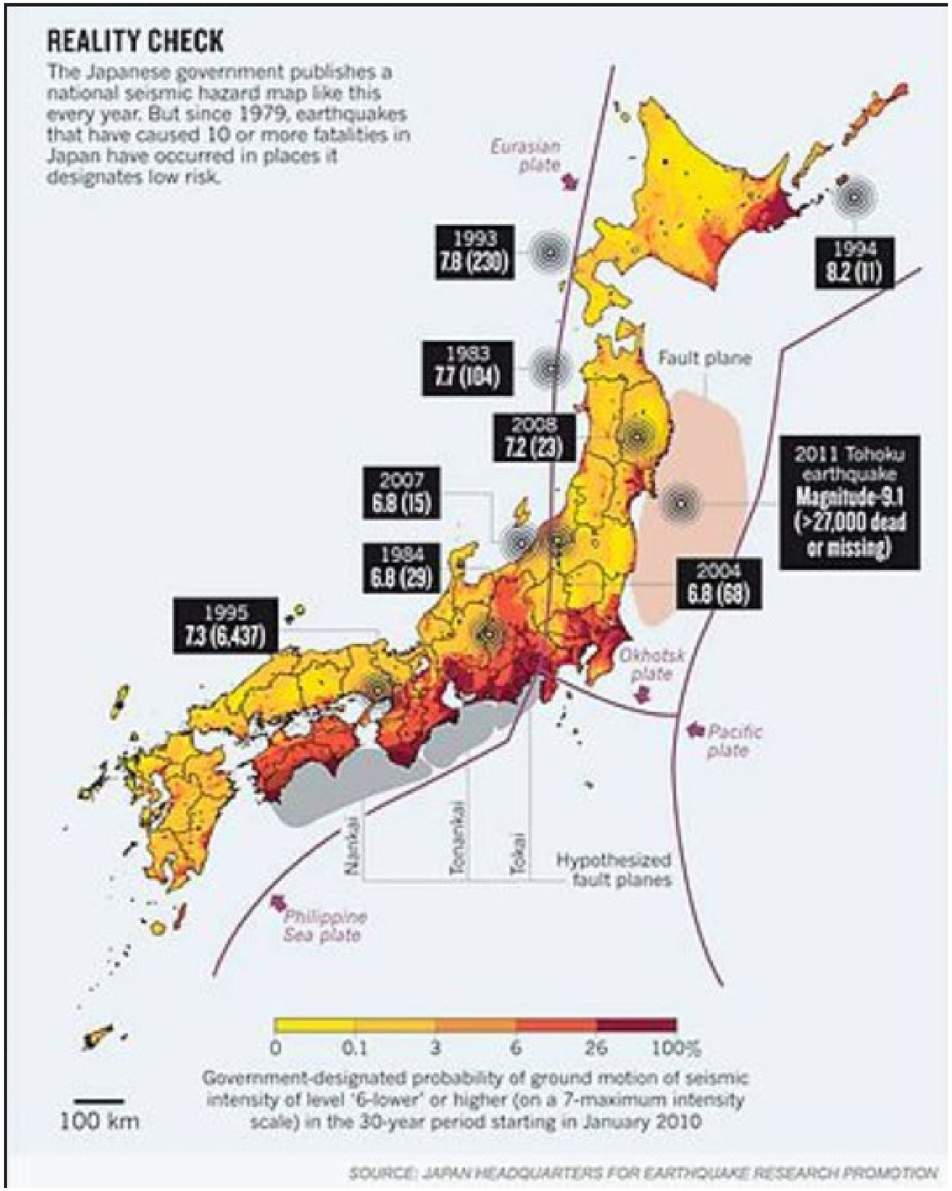
Inland earthquakes from Toda & Awata (EPS, 2007)

Probabilistic Seismic Hazard Assessment

Tom Hanks: “PSHA is a formalism for calculating ground-motion probabilities of exceedance, or *hazards*.”

HOWEVER …

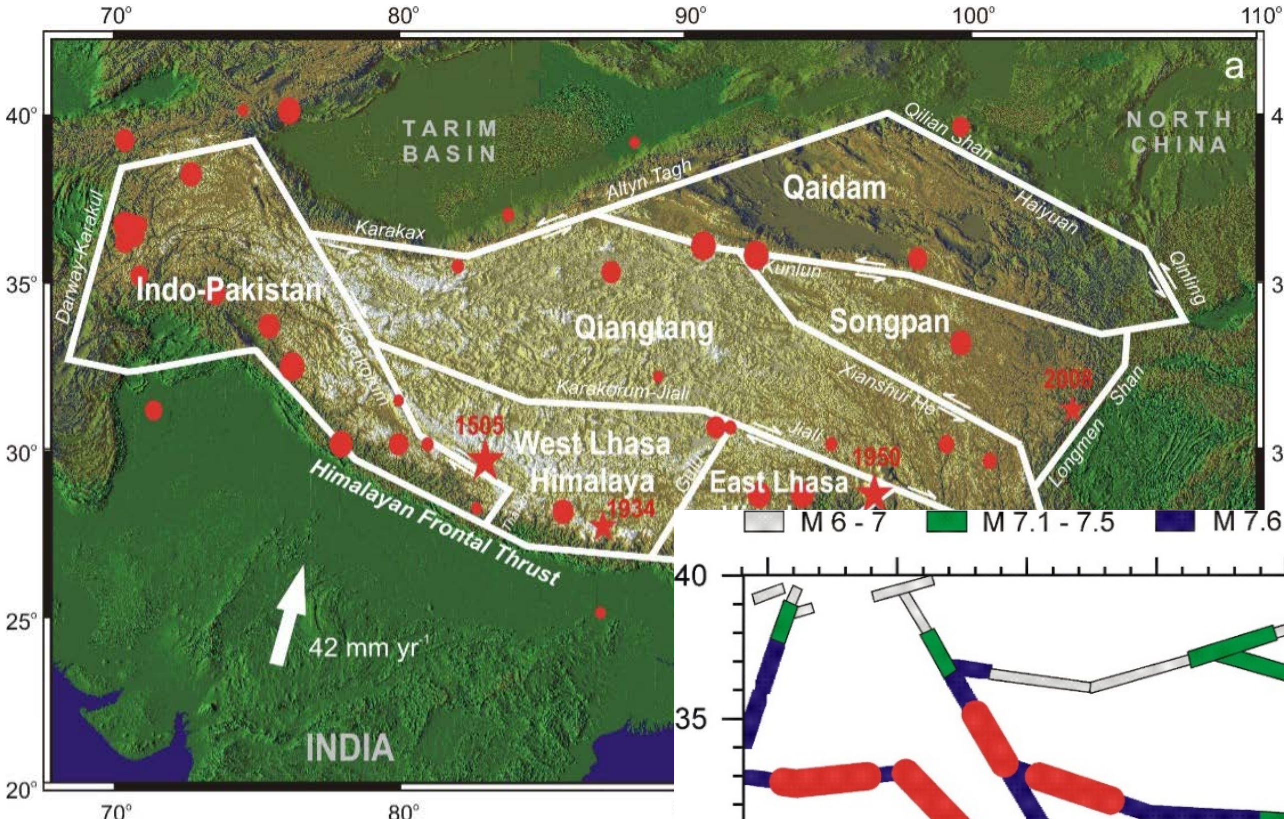
The probability of exceedance has NO relation to hazard defined as a natural event (e.g. an earthquake) that “may cause loss of life … and property …” (*from the terminology accepted by the United Nations General Assembly*)



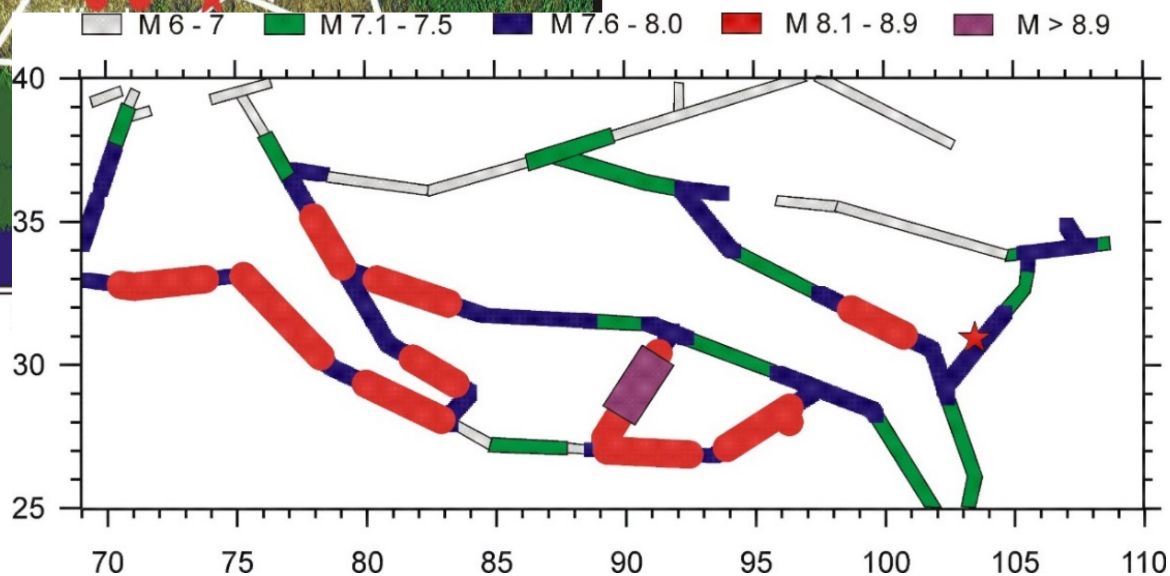
Geller, Nature, 2011

Can probabilistic seismic hazard forecasts do a better job than they do today?

Seismic hazard forecasting using an earthquake simulator (BAFD model for the Tibet-Himalayan region)

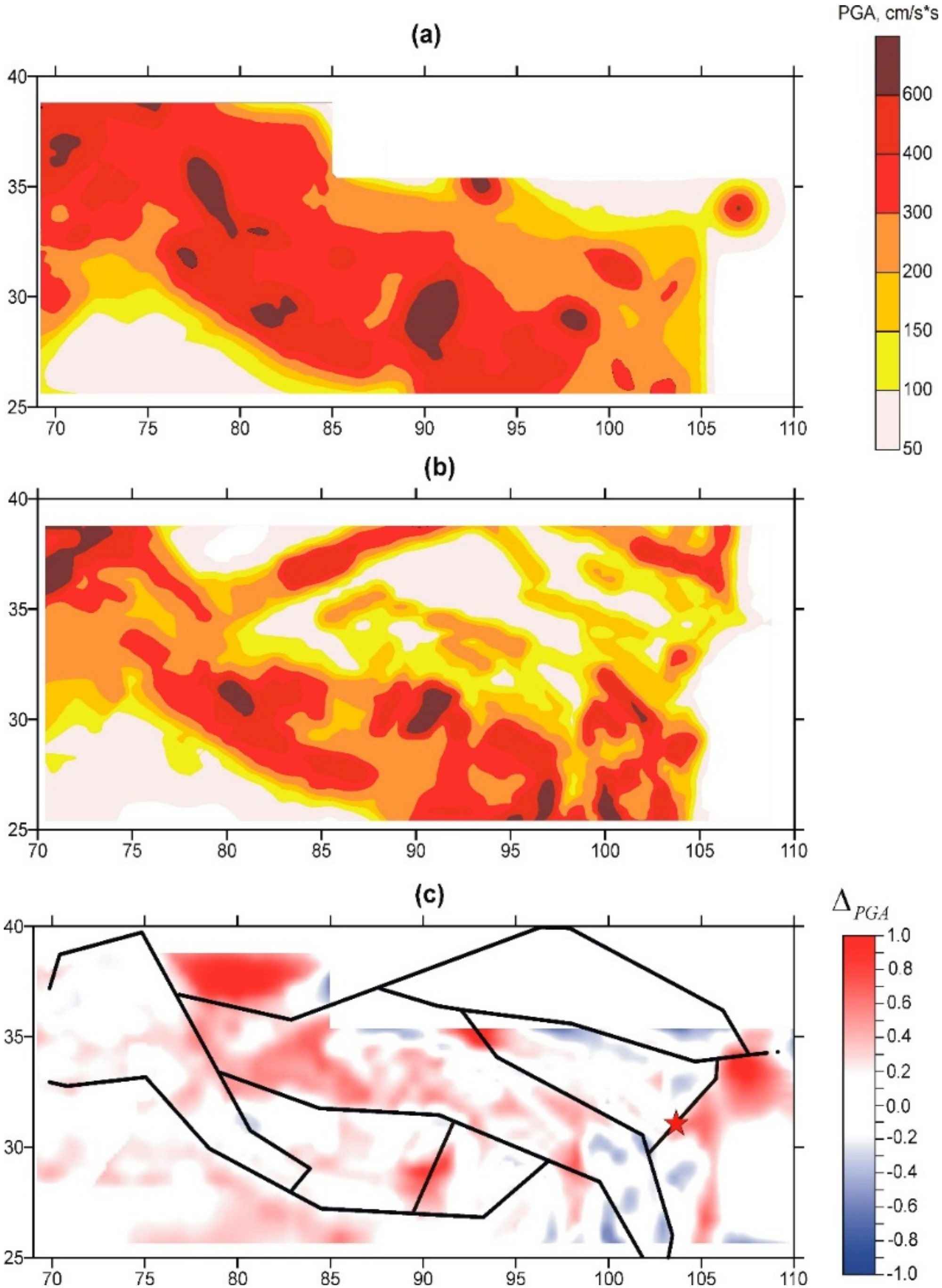


(Ismail-Zadeh et al., EPSL, 2007)



Distribution of maximum magnitudes of the earthquakes predicted by BAFD models

Seismic hazard using an earthquake simulator (the BAFD model)

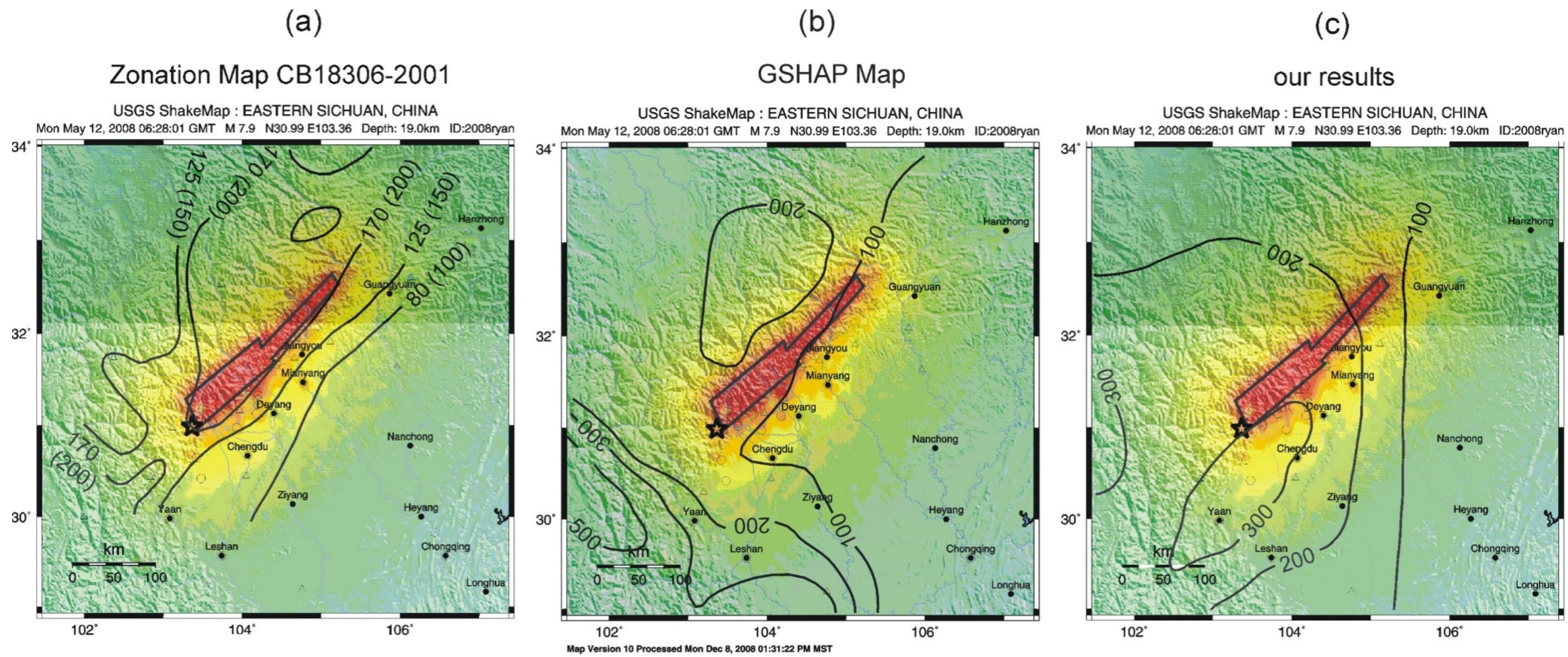


Using regional earthquake simulations, it is possible to improve probabilistic seismic hazard analysis in terms of probabilities of exceeding of ground motion for a specific time period.

PGAs for the return period of 475 years obtained (a) using the enhanced catalogue of recorded and simulated earthquakes and (b) from the Global Seismic Hazard Assessment Program (GSHAP) data. (c) The difference between two ground motion assessments (in log10 scale). Black lines are the fault system used in the BAFD models. Red star is the position of the 2008 Wenchuan earthquake

(Sokolov and Ismail-Zadeh, Tectonophysics, 2015)

Comparison of PSHA maps for Eastern Sichuan



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

(a) Chinese Seismic Code; rock (soil) **170 (200) cm/s^2**

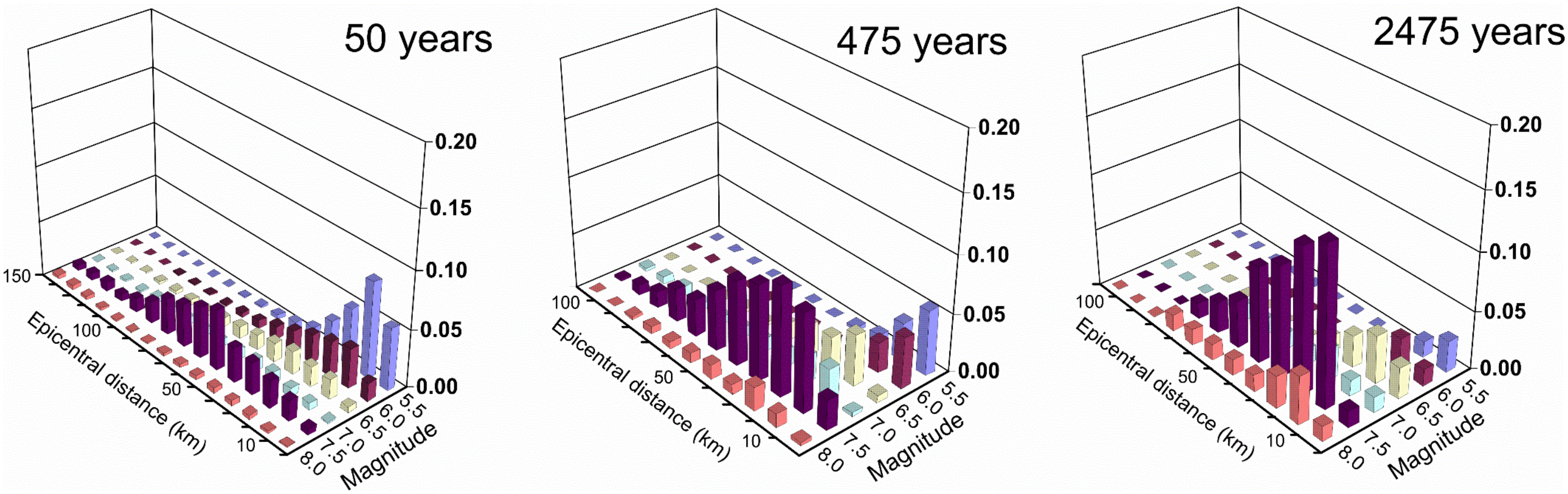
(b) GSHAP; rock **100 - 150 cm/s^2**

(c) Our results; rock **250 - 300 cm/s^2**

(Sokolov and Ismail-Zadeh, Tectonophysics, 2015)

Deaggregation

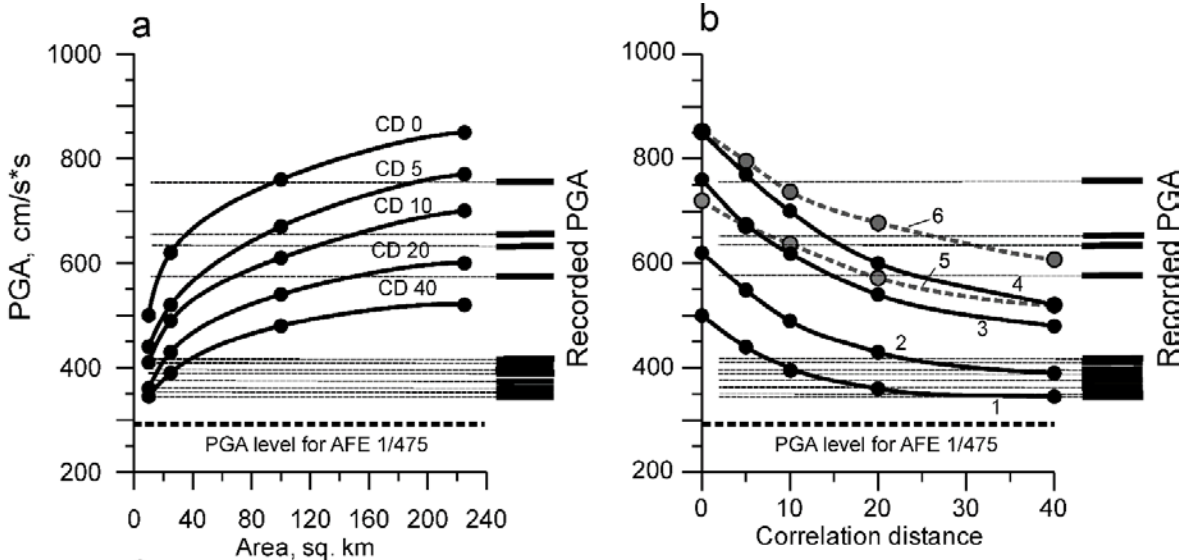
Hazard curves provide the combined effect of all magnitudes and distances on the probability of exceeding a specified level of ground motions. To investigate which events are the most important for the hazard at the specified level, the hazard curve is to be deconvolved to find contributions from different earthquake scenarios.

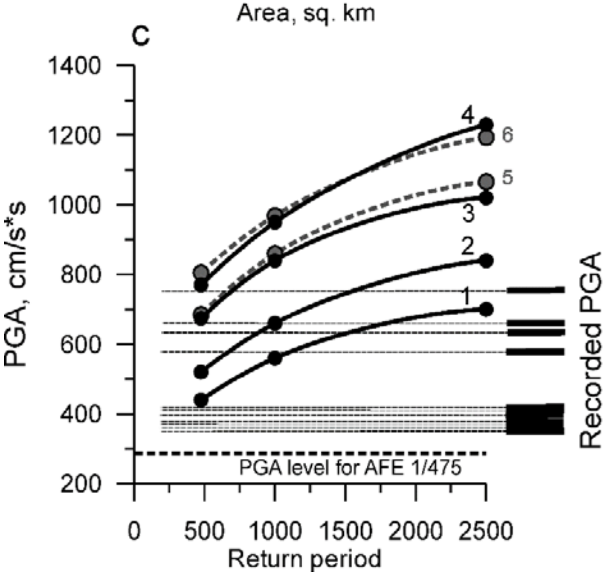


The contribution of different magnitude - distance bins to the PGA value in a site close to the epicenter of the 2008 Wenchuan earthquake calculated from composite (recorded and simulated) catalogs.

(Sokolov and Ismail-Zadeh, Tectonophysics, 2015)

Multiple-site (MS) hazard analysis





The 2008 Wenchuan earthquake. PGA for MS hazard estimations in a particular area (black dots and solid thick lines) and along linear object (gray dots and dashed thick lines), and comparison of the estimations with PGA recorded in epicentral area (thick short segments in the right side of graph mark the PGA levels). Dots show individual MS hazard estimations, and lines denote spline interpolation between the estimations.

(a) Dependence on the size of area. MS hazard estimations for return period 475 years and for different within earthquake correlation models (correlation distances, CD): 0 km, 5 km, 10 km, 20 km, and 40 km.

(b) Dependence on the within earthquake correlation distance. MS hazard estimations for return period 475 years and for different size of area: (1) 10 km^2, (2) 25 km^2, (3) 100 km^2, (4) 225 km^2; and length of linear object: (5) 50 km, (6) 100 km.

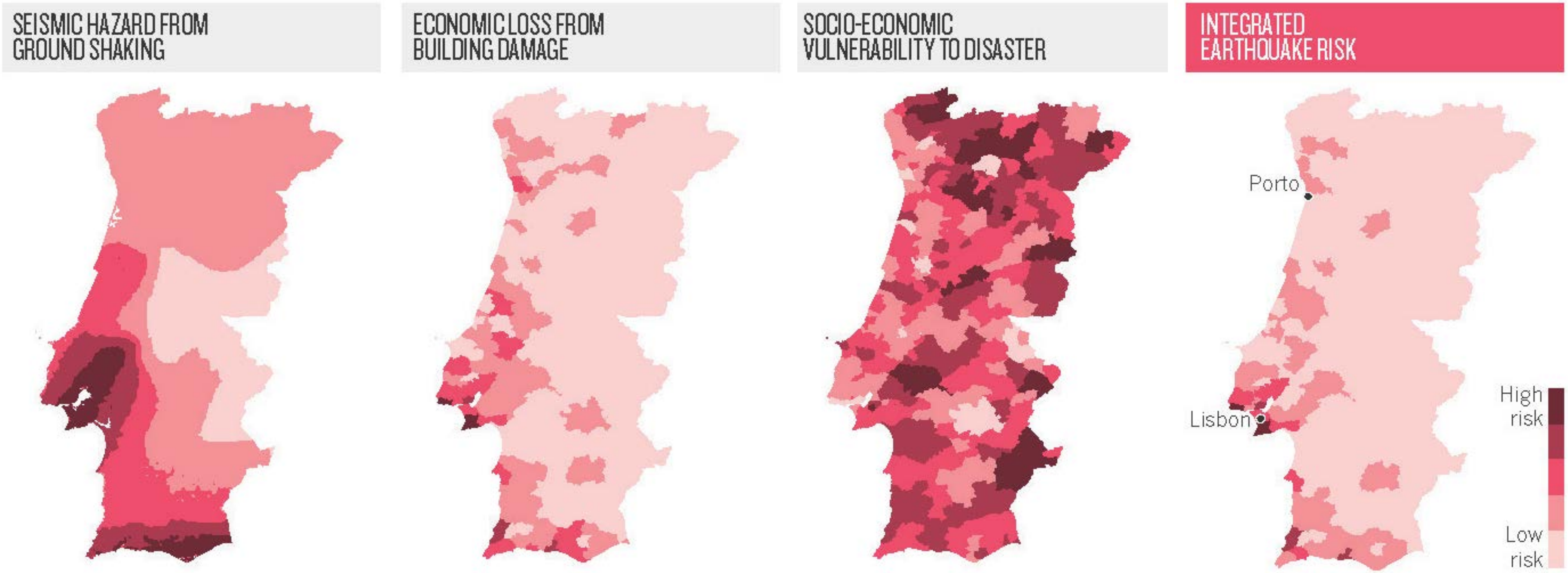
(c) Dependence on return period, within earthquake correlation CD = 5 km. MS hazard estimations for different size of area (1) 10 km^2, (2) 25 km^2, (3) 100 km^2, (4) 225 km^2, and length of linear object: (5) 50 km, (6) 100 km.

(Sokolov and Ismail-Zadeh, BSSA, 2016)

WHY
does an earthquake turn to become disasters?

Risk = Hazard $\otimes$ Vulnerability $\otimes$ Exposure

The Global Earthquake Model has tools to assess earthquake risk by combining data on ground shaking, construction practices and socio-economic vulnerability. An example from Portugal shows the integrated risk from a magnitude-8 earthquake such as the one that destroyed Lisbon in 1755.



Natural scientist approach

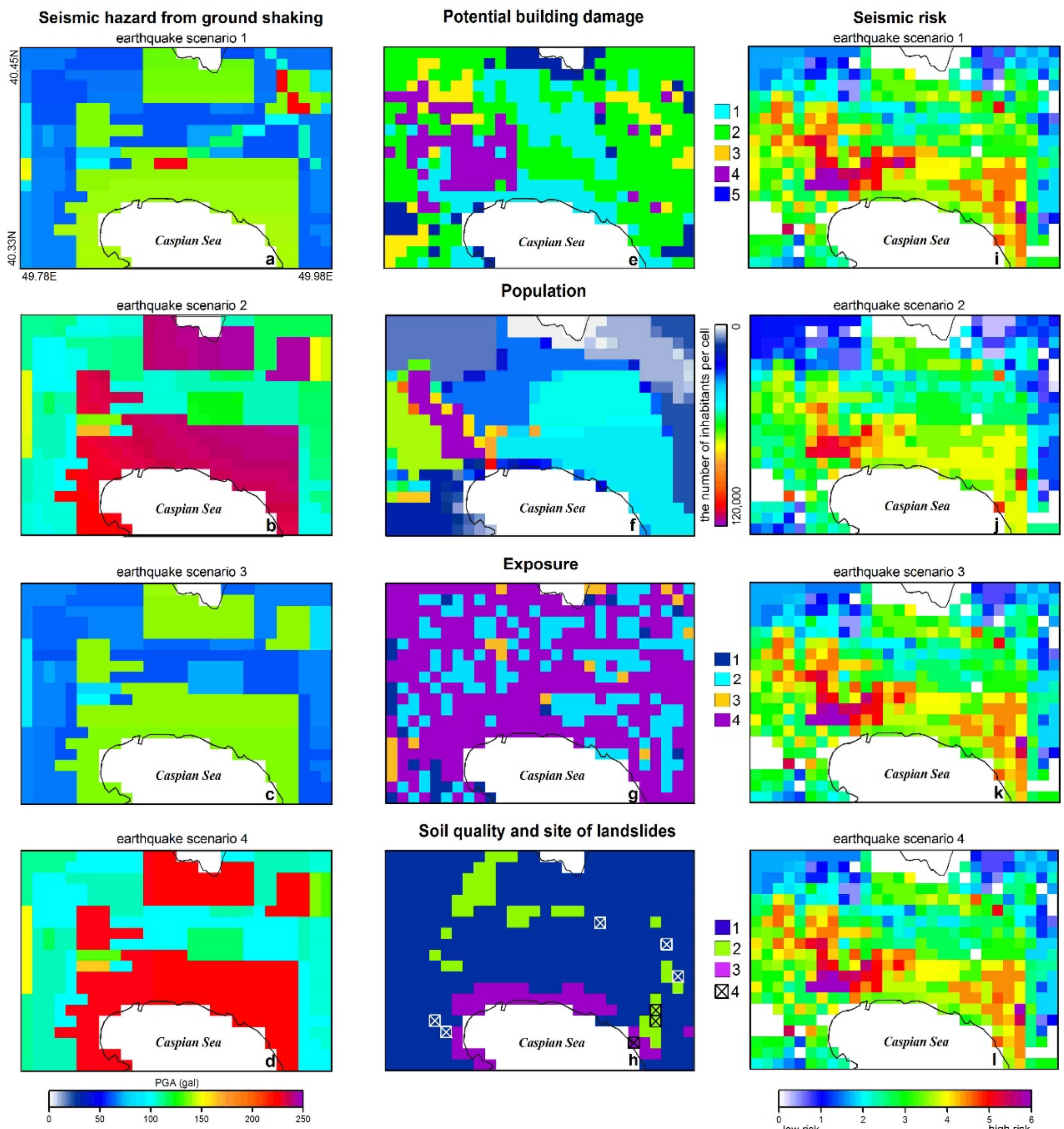
Engineering approach

Social scientist approach

Integrated approach

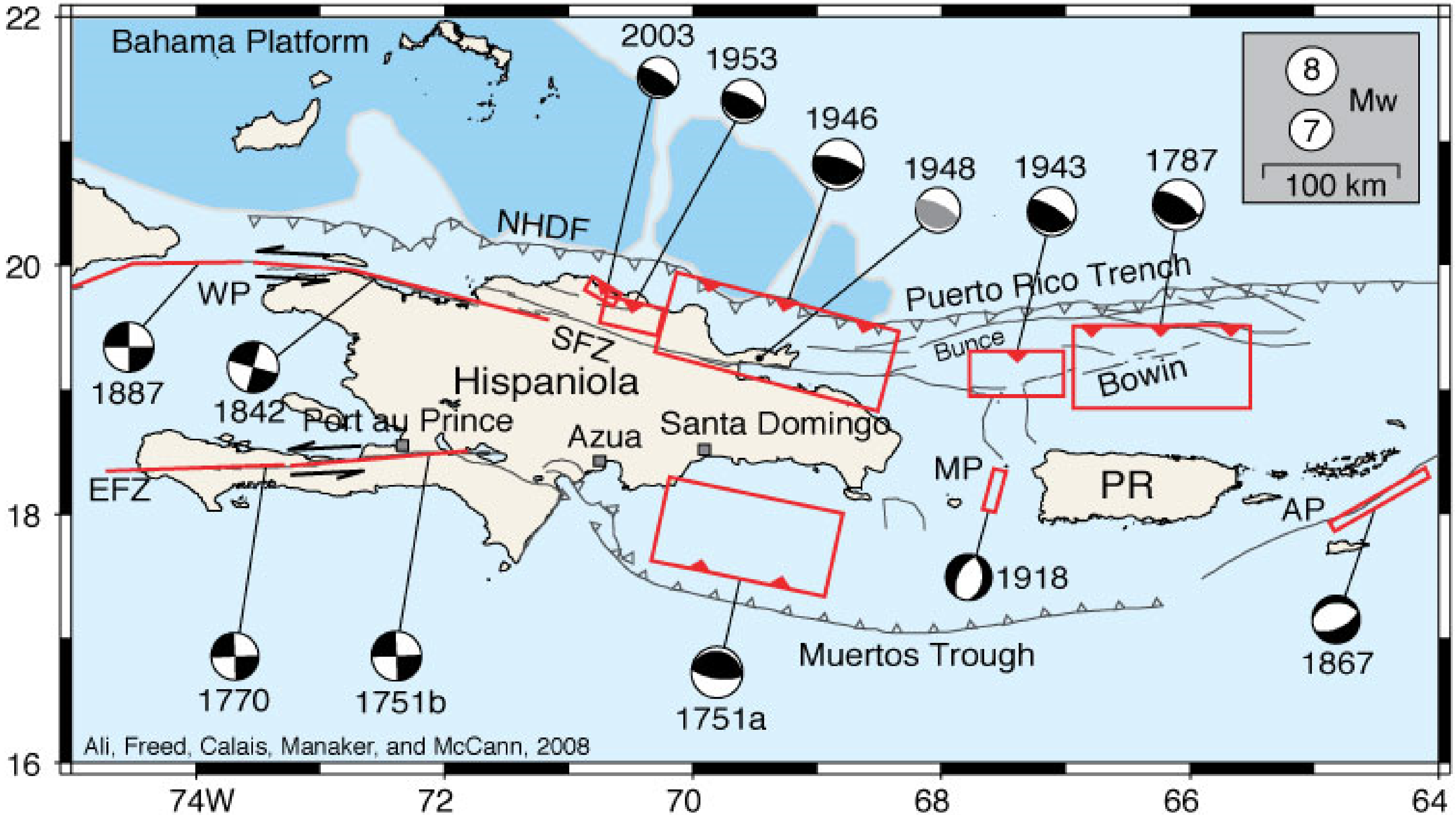
Baker, Nature, 2013

Risk = Hazard ⊗ Vulnerability ⊗ Exposure



Babayev et al., NHESS, 2010

Scientific Awareness

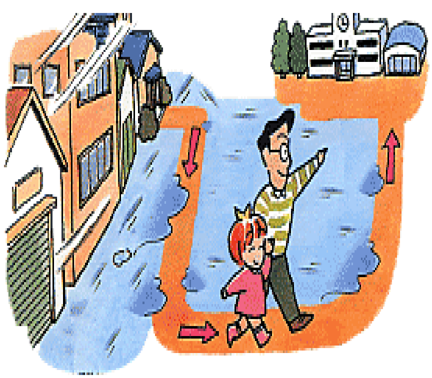


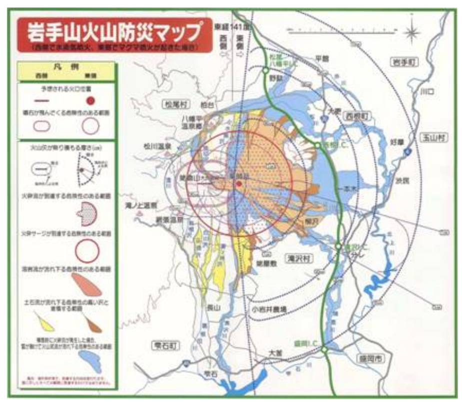
Scientists knew that the region near Port au Prince experienced strong earthquakes in the past. Why was this information not used by the authority to reduce disaster risk?

Public Awareness and Preparedness

Without having the scientific awareness raised, no political and governmental actions are possible. Here there is a large room for geoscientists to take responsibility.

Safe Evacuation Route





Understanding of Hazardous Areas

Appropriate Risk Awareness of Local Communities

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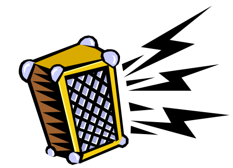


Early Warning

\=

Safe Evacuation

Courtesy of UNISDR

- **Earthquakes do not kill people, but buildings (irresponsibility, ignorance, corruption …)**

The 1 November 1755 Great Lisbon Earthquake.
More than 250 years ago scientists and philosophers understood that buildings kill people.
Construct well – save your life!

Kant (1724–1804)

"If humans are building on inflammable material, over a short time the whole splendour of their edifices will be falling down by shaking." (Kant, 1756)

The 2010 Haiti M=7.0 earthquake

- **Earthquakes do not kill people, but buildings (irresponsibility, ignorance, corruption …)**

As an example, not large earthquake in northwestern Iran led to disaster 11 August 2012

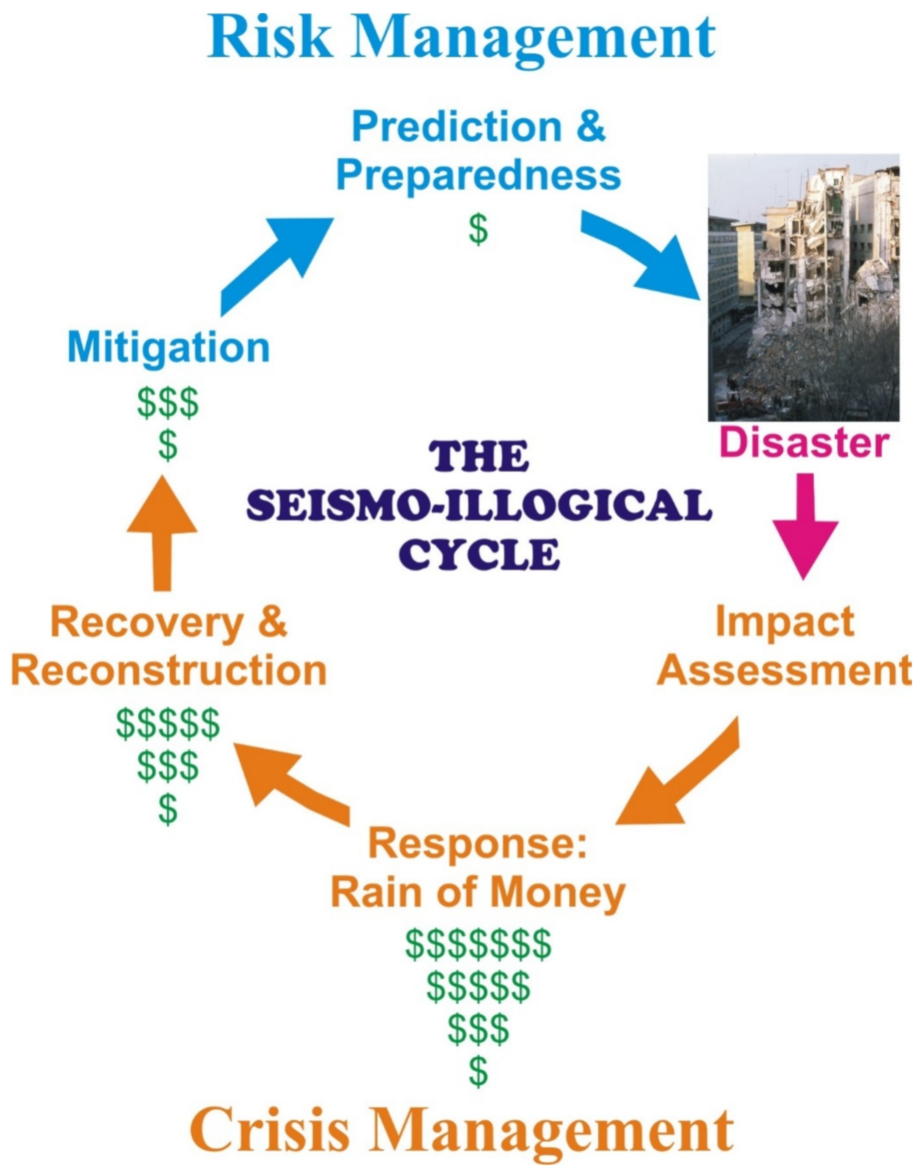
Economics of Disaster Risk Management

"If about 5 to 10% of the funds, necessary for recovery and rehabilitation after a disaster, would be spent to mitigate an anticipated earthquake, it could in effect save lives, constructions, and other resources."

(Ismail-Zadeh, OECD Workshop «Earthquake Science and Society», Potsdam, 2006)

"The tendency to reduce the funding for preventive disaster management of natural catastrophes rarely follows the rules of responsible stewardship for future generations, neither in developing countries nor in highly developed economies"

(Ismail-Zadeh and Takeuchi, 2007, Nat. Hazards)



(Ismail-Zadeh, 2010)

Despite the significant progress in natural hazards research, disasters triggered by geohazard events continue to grow in impact mainly due to vulnerability.

In many regions, geohazards are becoming direct threats to national security because their impacts are amplified by rapid growth of population, and unsustainable development practices both of which increase exposure and vulnerabilities of communities, capital, and environmental assets.

Reducing disaster risk using scientific knowledge is a foundation for sustainable development.

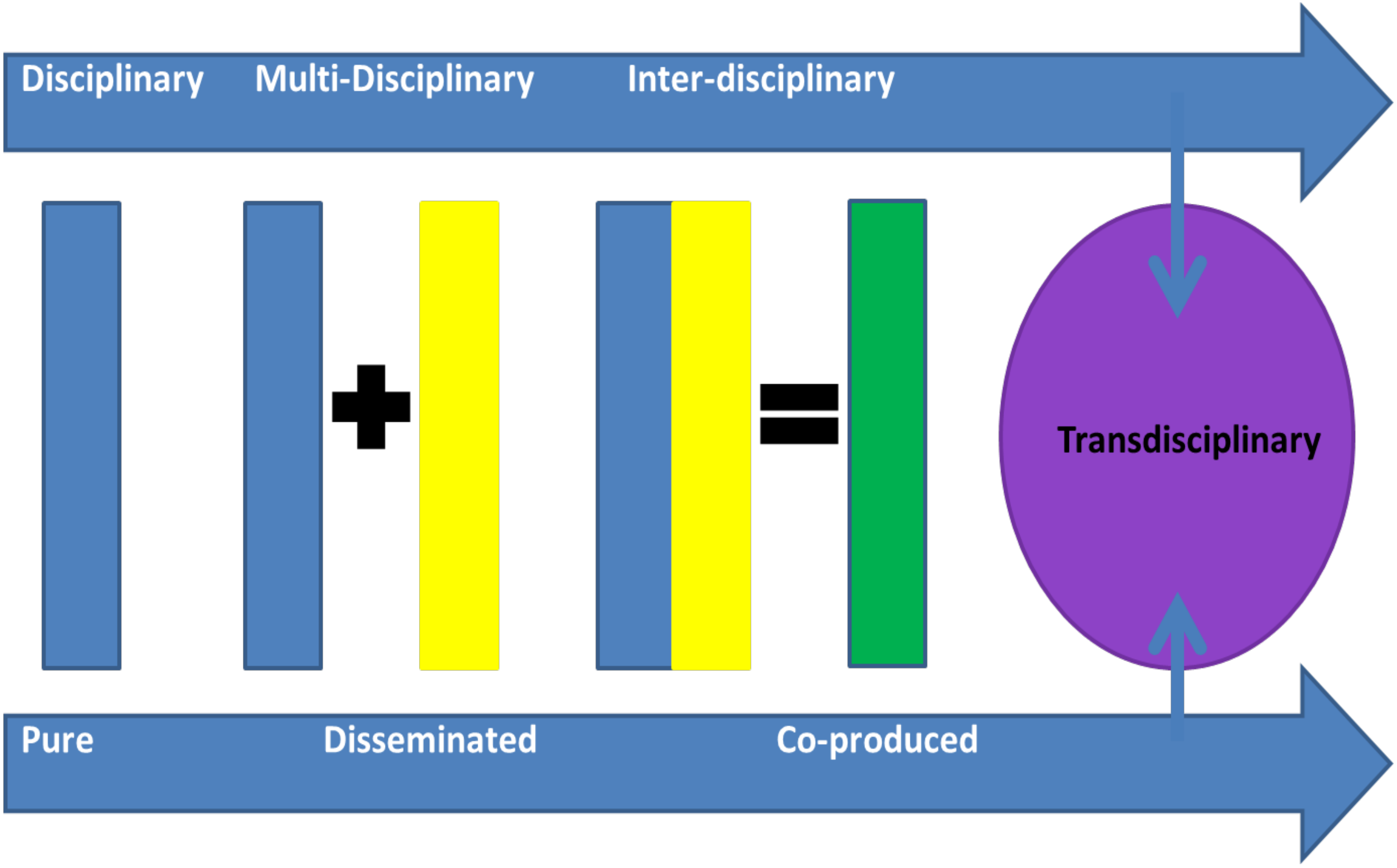
(Cutter et al., Nature, 2015)

WHY, despite a great progress in science & technology, do disasters due to natural events happen at such a catastrophic level?

John Godfrey Saxe's (1816-1887) fable based on the Indian legend

So oft in theologic wars, The disputants, I ween,
Rail on in utter ignorance Of what each other mean,
And prate about an Elephant
Not one of them has seen!

Transdisciplinary Science for DRR



(Ismail-Zadeh et al., 2017)

Co-design and co-production

What society **expects** to get from scientists?
(risk perception / uncertainties)

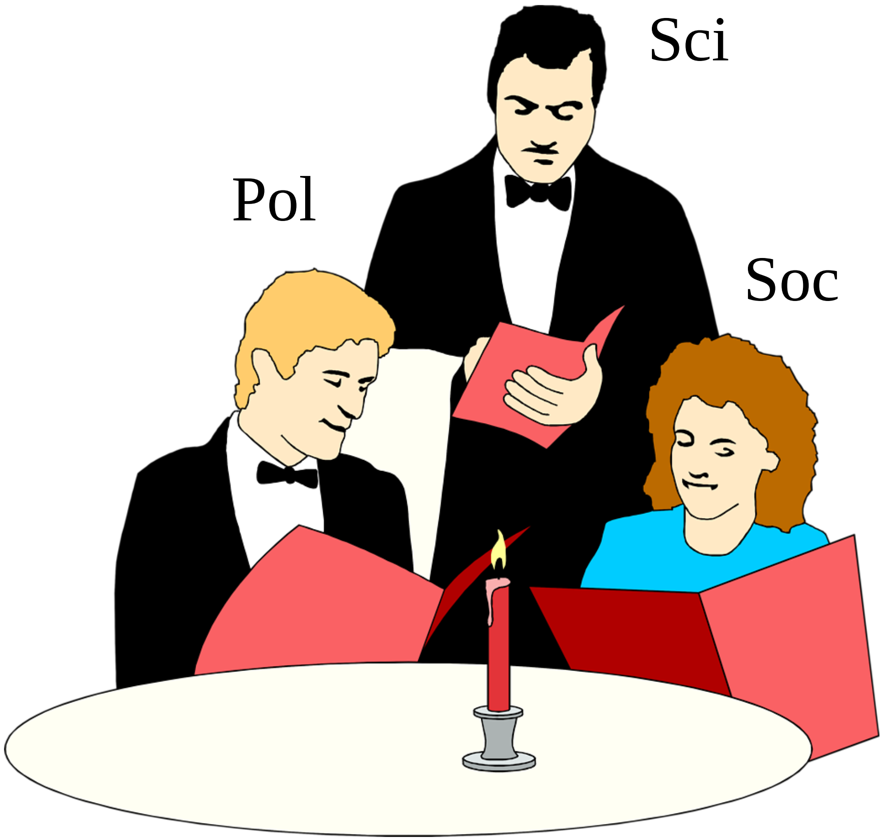
What policymakers **needs** from scientists?
(individual approach / interest for investment / short-term in power)

What scientists **can offer** society and policymakers?
(hazard and predictions with uncertainties /
but wise thoughts and engineering solutions)

Co-design and co-production

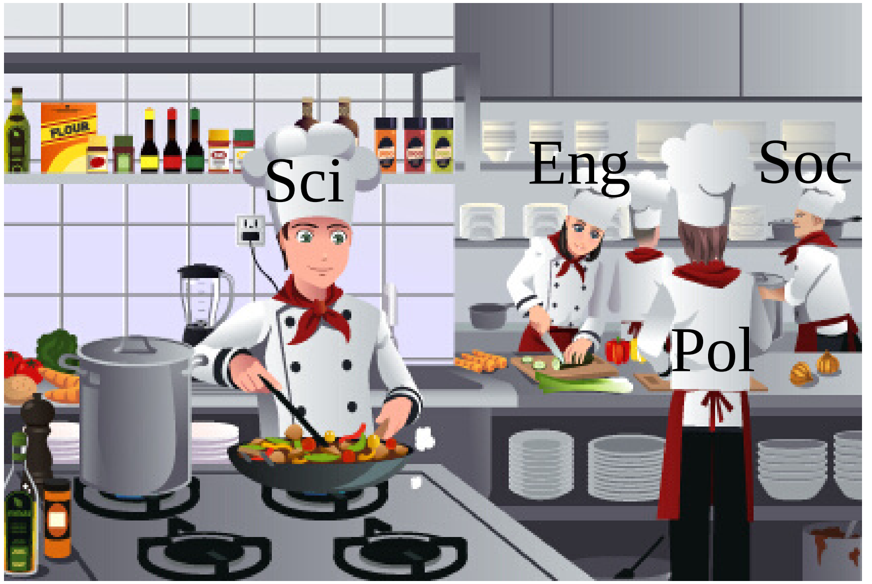
A co-production scheme (scientists-policymakers for society) is much complicated, but could be expressed by the following flow-chart:

- Scientists provide a "menu" of the knowledge available to help for decision making;
- Policymakers express their need, and order a "meal" from the scientific "menu"; a limited budget usually imposes significant limitations on the willingness of policymakers to pay for disaster reduction due to extreme natural events;



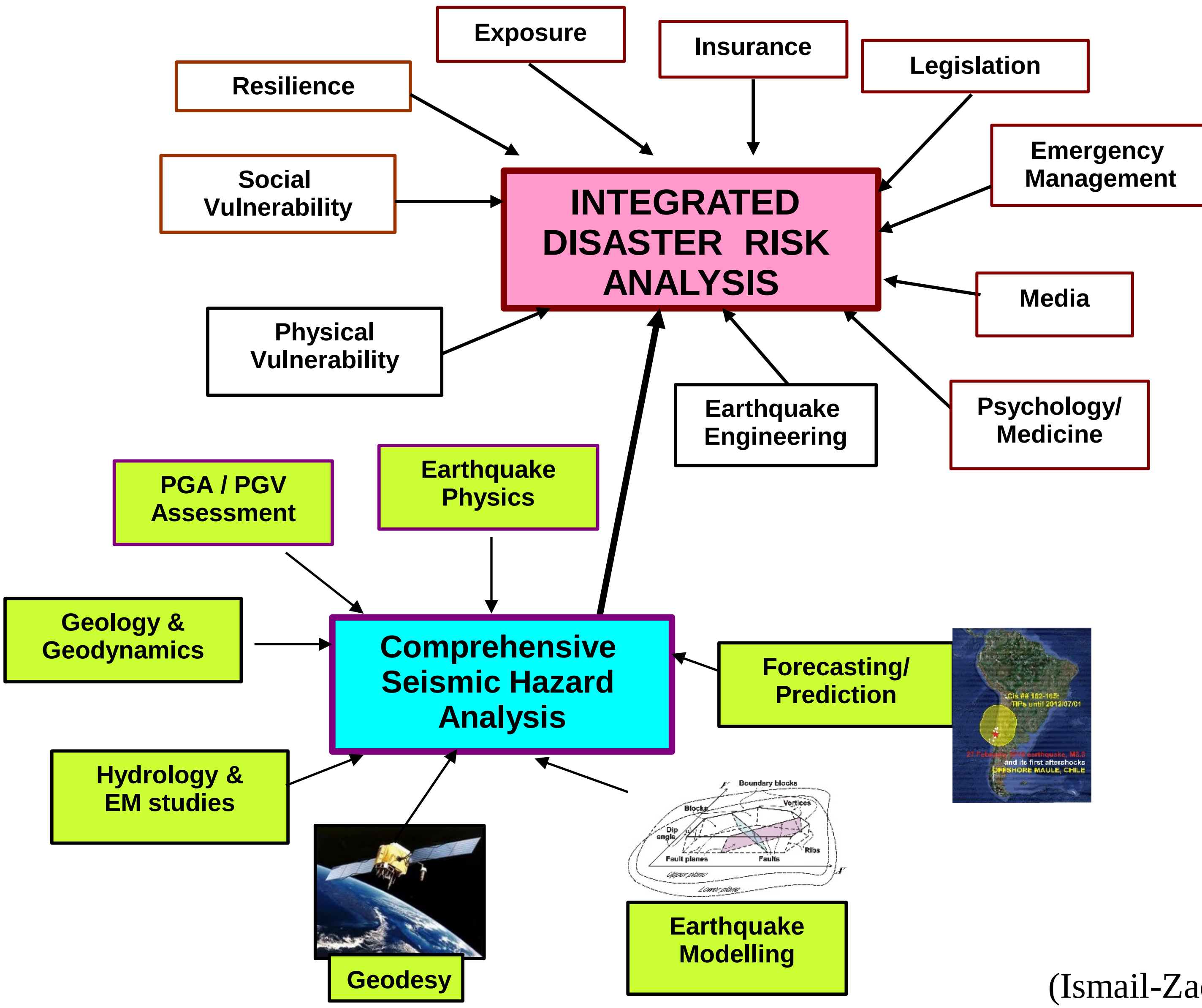
Co-design and co-production

- Scientists and engineers together with other stakeholders work ("cook the meal") with the principal aim to assist policymakers and society in reduction of disaster risks at local, national, regional, and global levels;



- The "meal", that is, new knowledge, risk assessments, and recommendations, is utilized by preventive measures to mitigate disaster risks. Hence, ***making the knowledge to be useful and used*** (Boaz and Hayden, 2002)

How can we reduce seismic risk?
Via integrated risk analysis



(Ismail-Zadeh, CUP, 2014)

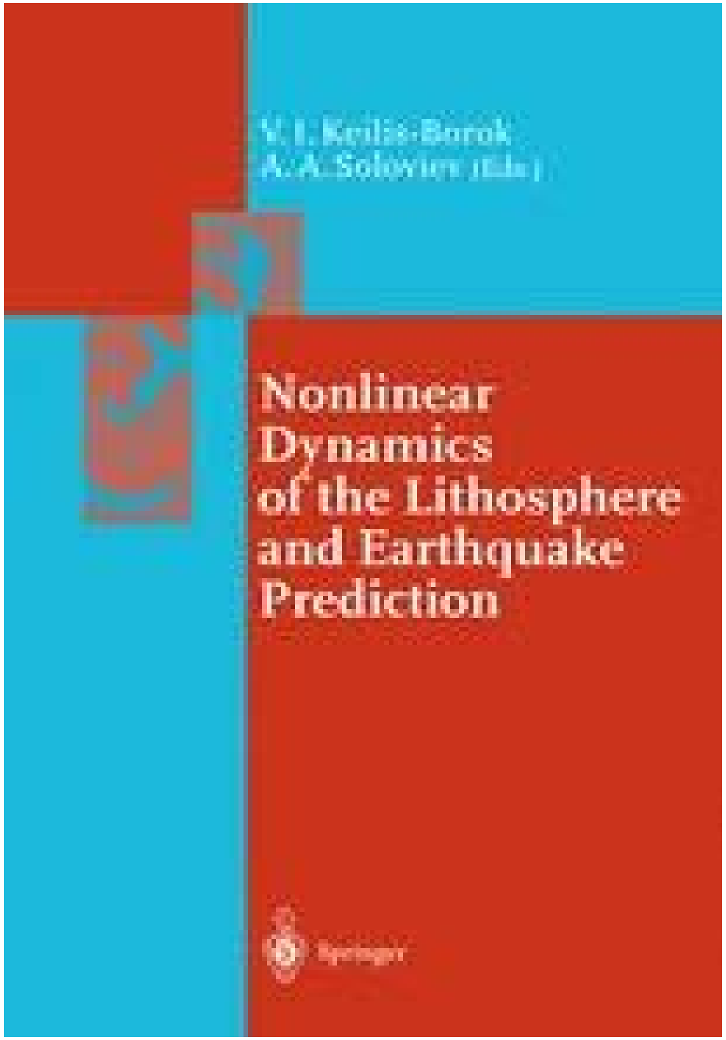
Conclusion: **the World without Disasters**

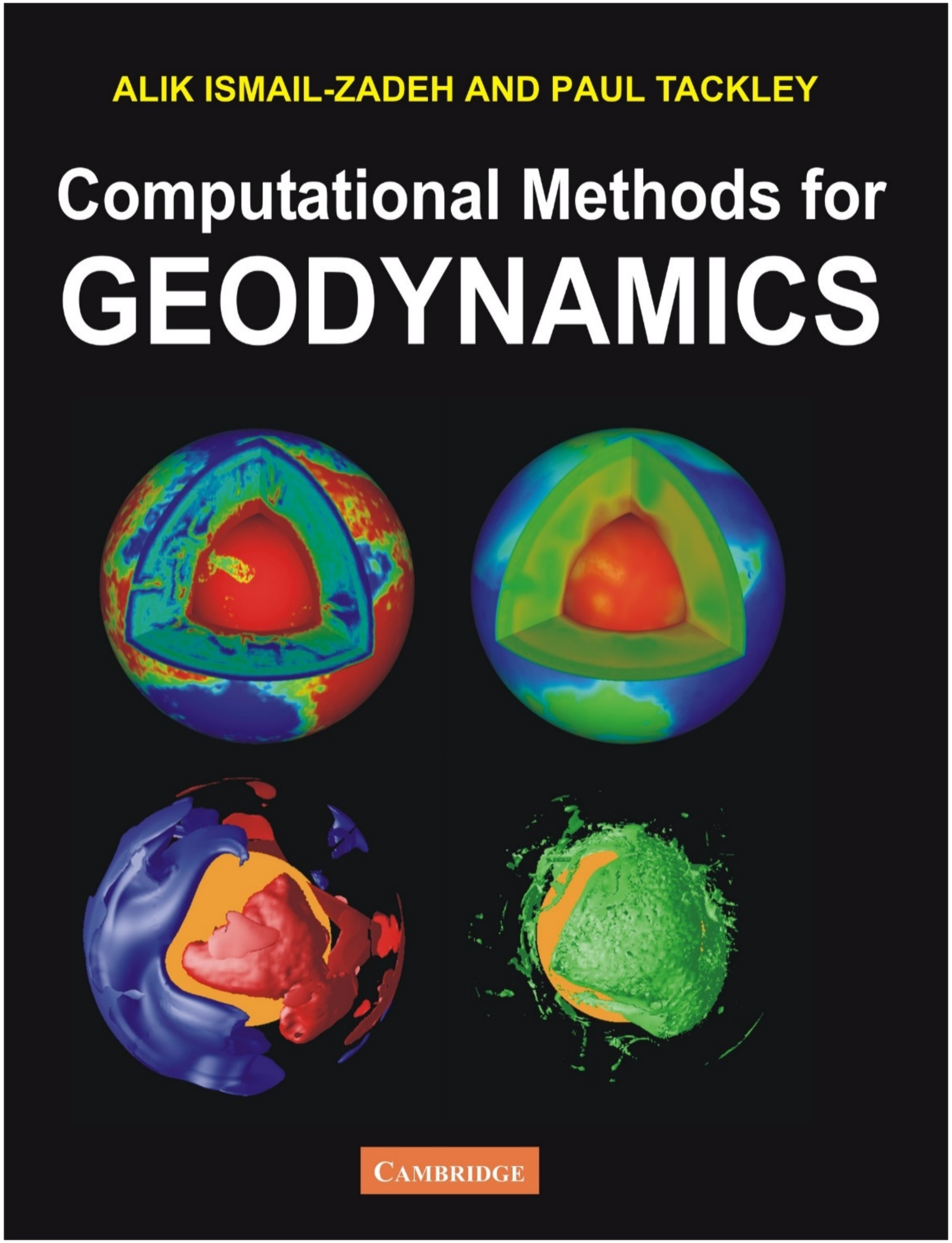
- Strengthening research and education in natural hazards an disaster risk research: from basic science of geophysical phenomena to disaster risk reduction and management
- Integrating geophysical, geological and geodetic studies in assessing natural hazards
- Enhancing observing and modeling capabilities and reducing predictive uncertainties in natural hazard research
- Dealing with multiple or concatenated events
- Hazards (e.g., earthquakes, volcanos, floods) cannot be reduced, but vulnerability (and hence enhancing resilience!)

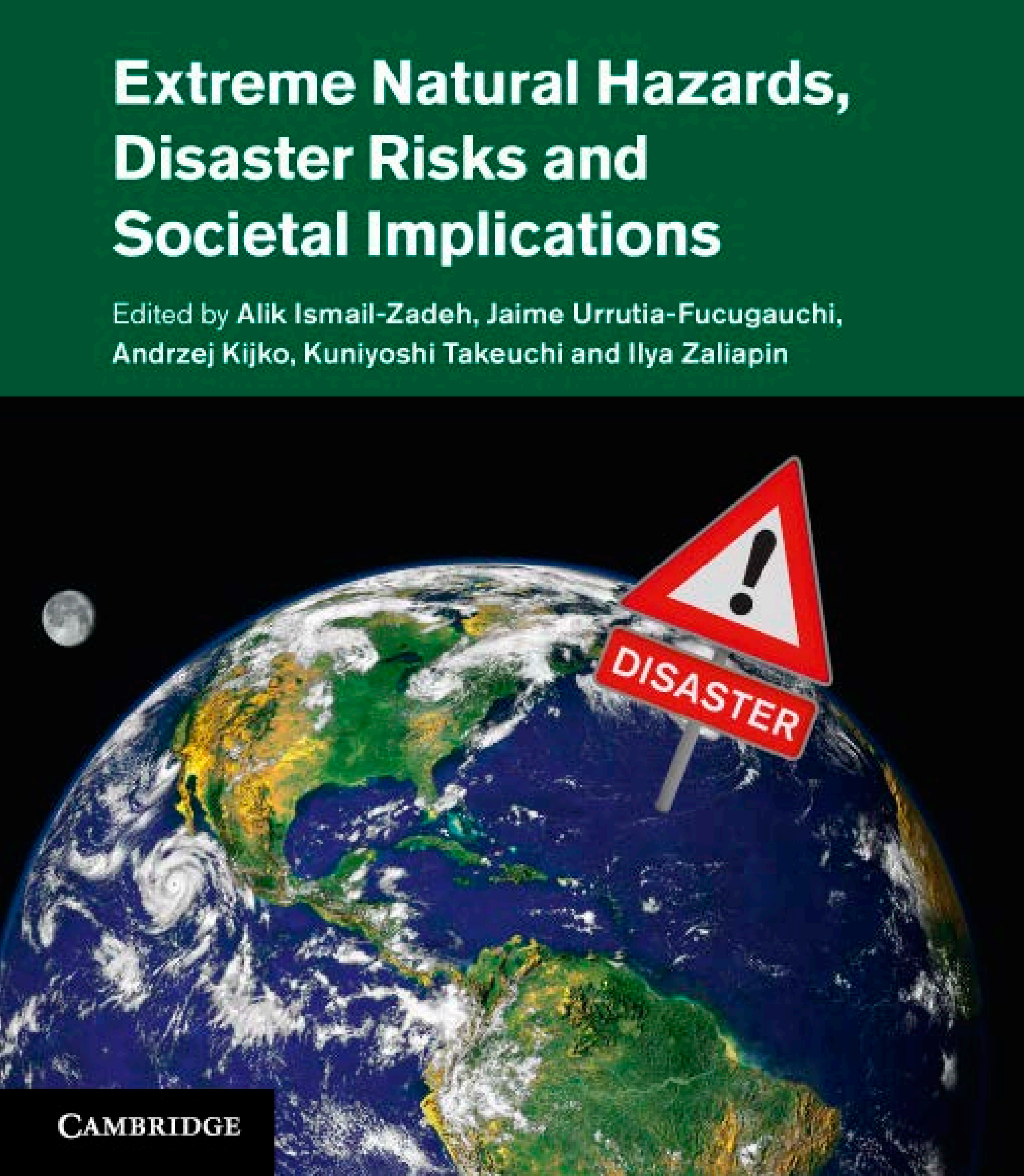
Conclusion: **the World without Disasters**

- Developing a trans-disciplinary link and integrating disaster risk research
- Building capacities and enhancing science education on NH and DR
- Improving awareness on extreme natural hazards and disaster risk
- Promoting communication of disaster risk at all levels
- Developing links to policy makers via disaster risk assessment
- Improving preparadness and disaster risk management

Details of the lecture can be found in the following books and research papers



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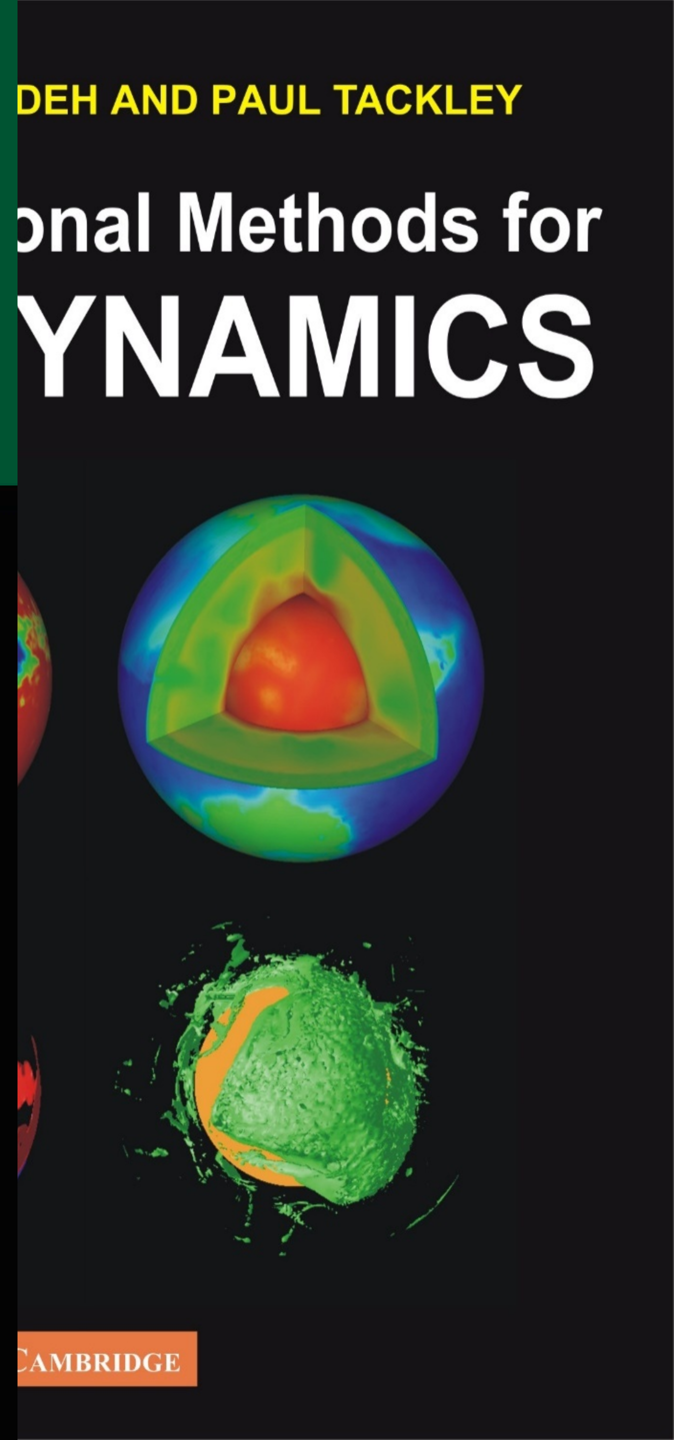
DISASTER
CAMBRIDGE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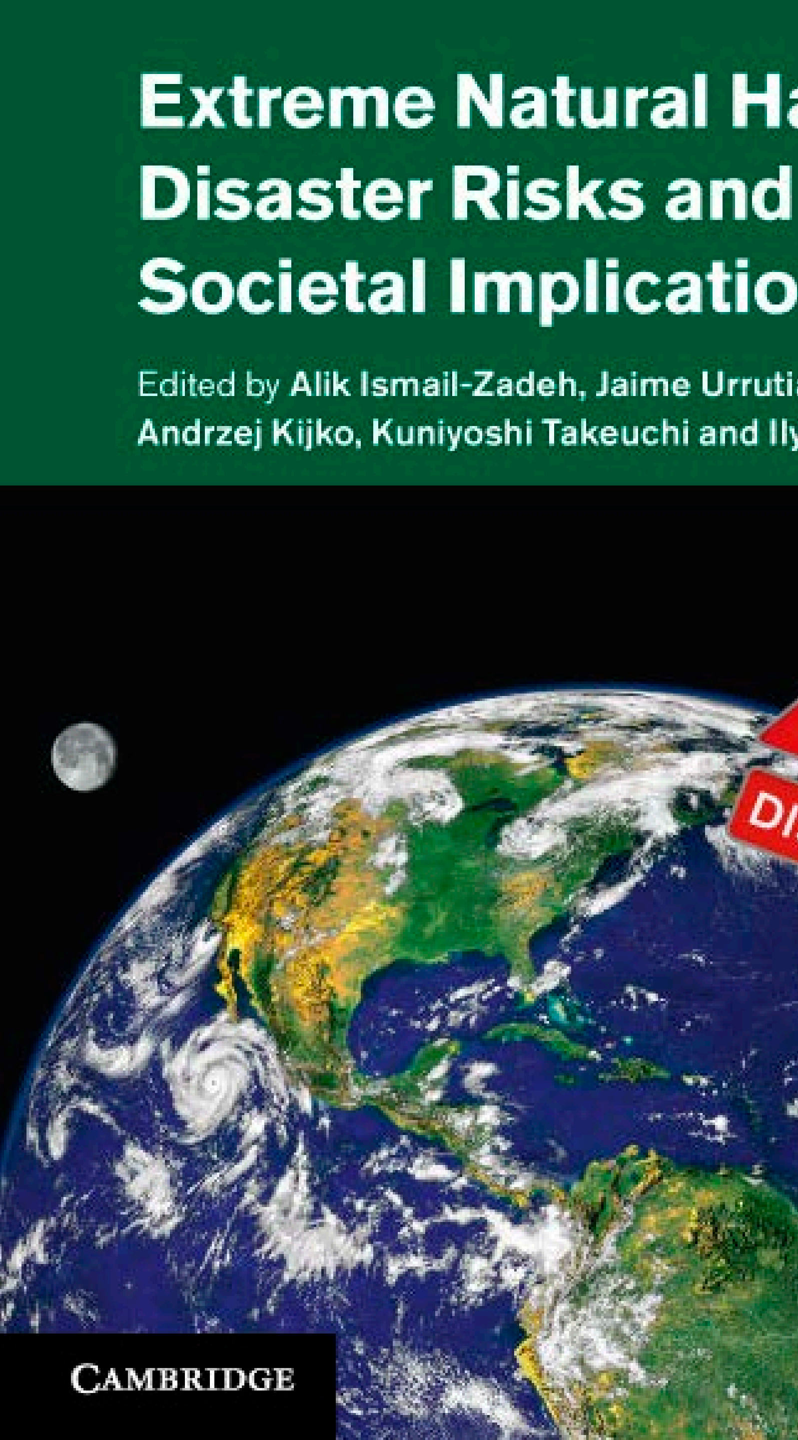
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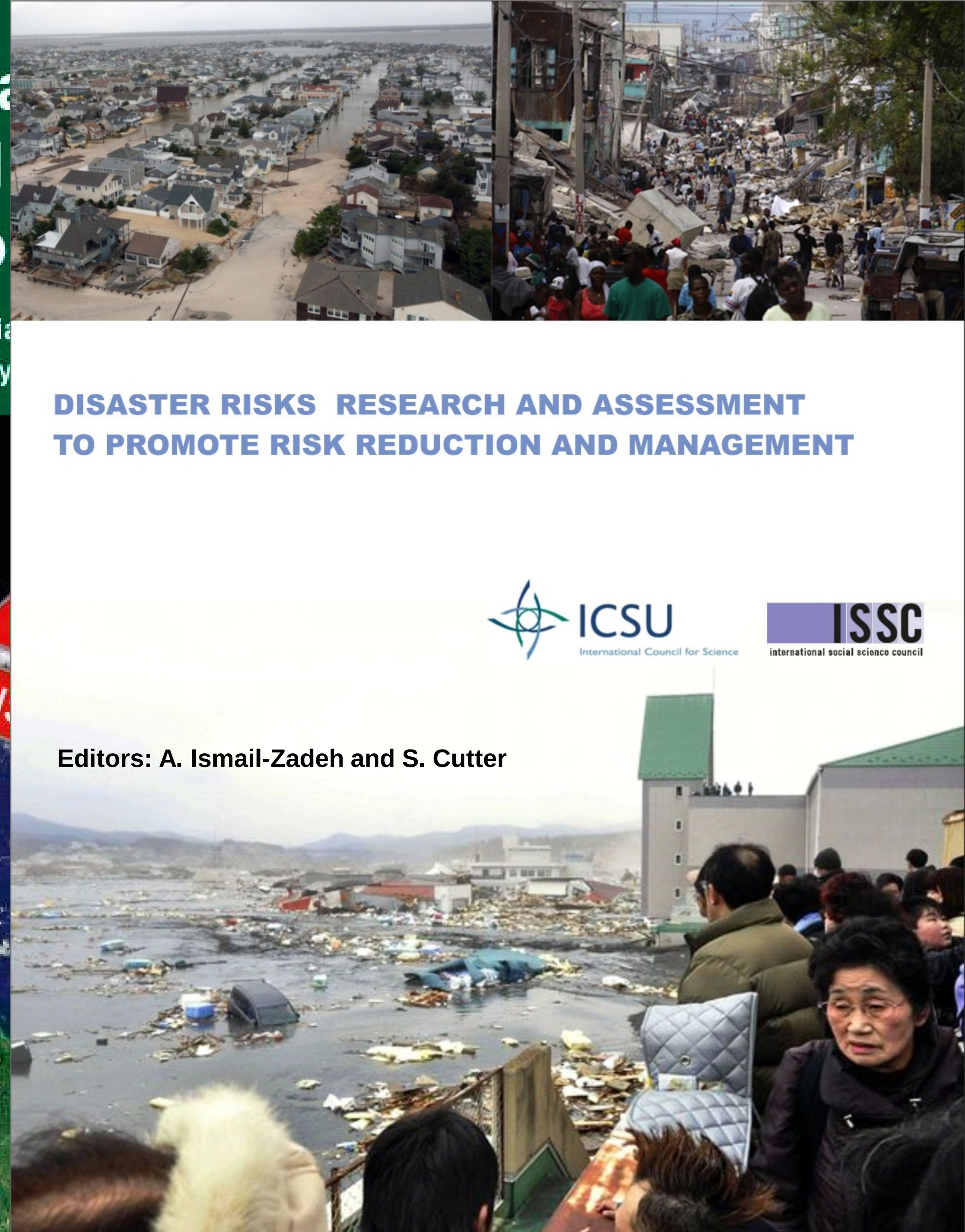
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TO PROMOTE RISK REDUCTION AND MANAGEMENT
ICSU
International Council for Science
ISSC
international social science council
Editors: A. Ismail-Zadeh and S. Cutter

Natural Hazards
March 2017, Volume 86, Issue 2, pp 969–988

Forging a paradigm shift in disaster science

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nature International weekly journal of science

Global risks: Pool knowledge to stem losses from disasters

Susan L. Cutter, Alik Ismail-Zadeh, Irasema Alcántara-Ayala, Orhan Altan, Daniel N. Baker, Salvano Briceño, Harsh Gupta, Ailsa Holloway, David Johnston, Gordon A. McBean, Yujiro Ogawa, Douglas Paton, Emma Porio, Rainer K. Silbereisen, Kuniyoshi Takeuchi, Giovanni B. Valsecchi, Coleen Vogel & Guoxiong Wu

17 June 2015

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A long journey toward seismic safety and sustainability

'Scientists in the 21st century … believed that natural events, which they called hazards, lead in many cases to tragedies in families and result in severe losses of lives and properties. They did not know well how to minimize or, as today, to eliminate disasters. We know it now (in the 22nd century). But we should thank them anyway that they thought about us and tried their best to reduce disasters and create a better future for us'

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